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A FURTHER STUDY OF TRIPHENYLBISMUTHINE DICHLORIDE CRYSTALS

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Some years ago,¹ a crystallographic and optical examination of triphenylbismuthine dichloride was made. It was found that the crystals belong to the orthorhombic system, having an axial ratio of $a:b:c=0.774:1:0.409$, and that they also exhibit the phenomenon of crossed axial dispersion. Furthermore, when examined in parallel polarized light along the b -axis, which is the acute bisectrix, they do not extinguish in the normal manner, but when brought into the extinction position, transmit a green light of the same wave-length for which the interference figure becomes uniaxial. This effect seemed to be due to rotatory polarization which could, of course, only occur in a crystal belonging to the holoaxial class of the orthorhombic system. A certain amount of evidence, based on face development and etching figures, for assigning the crystals to this class was obtained.

Some additional data on the variation of optical properties with wave-length and temperature have now been obtained. An x -ray study, while not elucidating the structure of the crystals, has definitely proved that they belong to the holoaxial class.

CRYSTALLIZATION OF TRIPHENYLBISMUTHINE DICHLORIDE

A stock of very pure triphenylbismuthine dichloride, melting at 141°C , was obtained by repeated recrystallization from acetone of the product prepared by the Eastman Kodak Company according to the methods described in the chemical literature. The crystals used in the investigation were obtained by the slow cooling of a warm acetone solution. Several hundred crops of crystals were examined; they all showed face development of the holoaxial type. Prismatic crystals of the type previously described were usually found. The bipyramidal type of crystals was not obtained, but now and again a variant of the prismatic type occurred. In these particular crystals, which are shown in Fig. 1, the dome (011) is

¹ G. Greenwood, *Mineral. Mag.* (1923), 20, 123; *Zeit. f. Krist.* (1924), 60, 311

absent, and the sphenoid ($1\bar{1}1$) has grown quite large. It was found possible to obtain etching figures on the pinacoid (010); etching was done by means of acetone. These etching figures are illustrated in Fig. 2. They show quite distinctly the absence of horizontal and vertical symmetry planes.

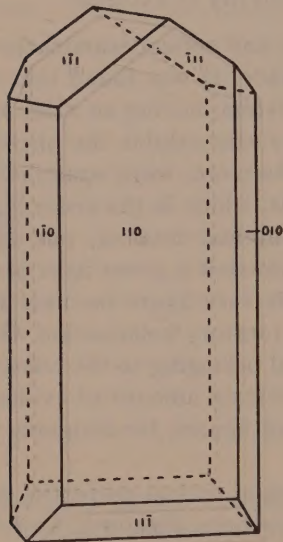


FIG. 1. Crystals of Triphenylbismuthine Dichloride.

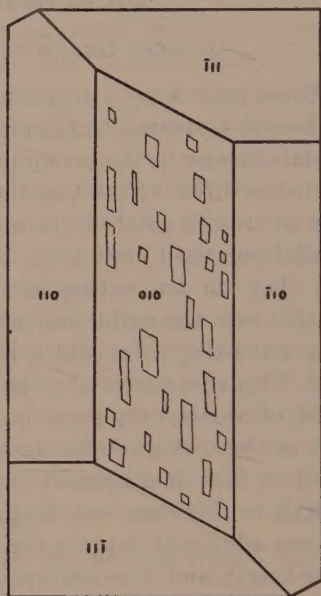


FIG. 2. Etching figures on the (010) face of Triphenylbismuthine Dichloride.

OPTICAL INVESTIGATION

In the previous investigation observations were only made in a few monochromatic lights of wave-lengths easy to obtain. Since a monochromator was now available, it was decided to study more carefully, using the very pure crystals, the variation of optic axial angle with both wave-length and temperature.

The method which was used for measuring the optic axial angle was that suggested by Mallard,² who showed that $D = K \sin E$, where $2D$ is the linear distance between the optic axes measured on a micrometer scale in the eyepiece of the microscope, $2E$ the apparent optic axial angle, and K a constant (the Mallard constant) depending on the lens system of the microscope. A crystal, having the (010) faces developed to a considerable extent, was carefully

² *Bull. Soc. Min. Fr.* (1882), 5, 77.

mounted on a glass slide so that the interference figure was as symmetrical as possible about the axis of the microscope. Any slight error due to lack of coincidence between the acute bisectrix and the microscope axis was eliminated by taking a second reading of D after the section has been rotated through 180° . The constant K was found by calibrating the instrument with a number of mica sections of known optic axial angles. The observations were made at a constant temperature of 23°C and the results are shown in Table I. Those values marked * represent angles in the plane (001); the other values are for angles in the plane (100).

TABLE I
VARIATION OF APPARENT OPTIC AXIAL ANGLE WITH THE WAVE-LENGTH.

Wave-length	2E	Wave-length	2E	Wave-length	2E
4700 Å	*92.6°	5400 Å	9.0°	6100 Å	73.8°
4800	*87.6	5500	30.4	6200	79.4
4900	*76.0	5600	41.4	6300	85.2
5000	*65.2	5700	50.0	6400	90.8
5100	*52.6	5800	59.0	6500	93.0
5200	*41.0	5900	65.2	6600	95.2
5300	*23.6	6000	69.4	6700	98.4
5378	0.				

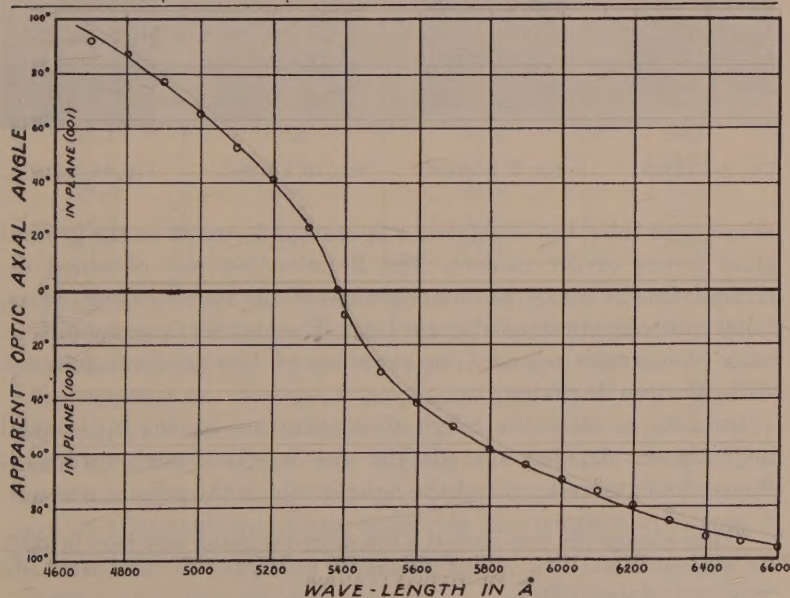
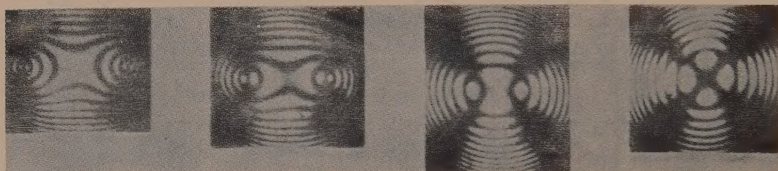
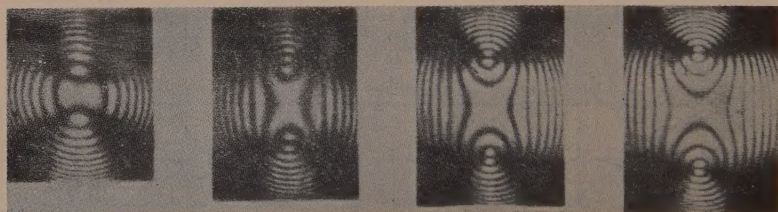


FIG. 3. Variation of apparent optic axial angle with wave-length: temperature constant.

These results are shown graphically in Fig. 3. The curve is similar in shape to that published previously, but because of the purity of the substance and the much larger number of measurements made, it is without doubt a truer representation of the facts.

The variation of optic axial angle with wave-length is also shown by the series of photomicrographs³ of interference figures, which is reproduced as Figs. 4-11. To obtain these photographs a petrographic microscope fitted with a photomicrographic camera was used. By adjusting the position of the eyepiece, in or out of the

FIG. 4. λ 4900Å.FIG. 5. λ 5100Å.FIG. 6. λ 5350Å.FIG. 7. λ 5400.FIG. 8. λ 5450Å.FIG. 9. λ 5800Å.FIG. 10. λ 6100Å.FIG. 11. λ 6450Å.

microscope tube, the interference figure was focussed on the ground glass screen of the camera. The illumination was obtained directly from the slit of the monochromator, the source of light being a 100 watt concentrated filament lamp. Even under these conditions each photograph required an exposure of two to three minutes with Wratten *M* plates.

In order to show the effect of temperature on the optic axial angle, it was decided to study the way in which temperature influenced the wave-length of the light in which the crystal was uni-

³ These photographs were made in a hot, badly ventilated, dark room in which the temperature was 27°C. At this temperature the crystals become uniaxial at a wave-length of about 5400 Å.

axial, rather than to keep the wave-length constant and investigate the actual change of angle with temperature. Furthermore the measurement of the wave-length at which the crystal becomes uniaxial is more accurate than the measurement of the optic axial angle itself. The monochromator, which had a direct reading wave-length drum, was accurately adjusted by setting the drum to give correct readings for the lines of a mercury arc. The observations at the lower temperatures were made at the temperature of the room, in certain cases on cold days with the windows open. The higher temperatures were obtained by an electrically heated stage having thermostatic control. The temperatures could be read to 0.1°C on a thermometer which fitted into the heated stage. The wave-length values are the means of six settings of the monochromator, three being made by approaching from the long wave-length side and three from the short. The setting could be made with an accuracy of about 5\AA . Table II contains the results.

TABLE II
VARIATION OF THE WAVE-LENGTH AT WHICH THE CRYSTAL IS
UNIAXIAL WITH TEMPERATURE.

Temperature	Wave-length at which the crystal is uniaxial	Temperature	Wave-length at which the crystal is uniaxial
7.0°C.	5313 \AA	28.0°C.	5405 \AA
11.5	5327	32.0	5415
14.1	5340	36.5	5440
16.0	5351	40.0	5457
19.0	5364	46.0	5483
23.0	5378	47.0	5486
25.0	5392	50.0	5499

These results are plotted in Fig. 12; they give a straight line. It is difficult to say whether the line would remain straight if it could be studied throughout a greater range. L. Brugnatelli⁴ made similar measurements on crystals of saccharine and found that the line showing the variation of wave-length at which the crystal is uniaxial with temperature was slightly curved. His temperature range was about 33°C and his wave-length range was 2600\AA ; in the case of triphenylbismuthine dichloride the temperature range is 43°C and the wave-length range 200\AA .

⁴ *Zeit. f. Krist.* (1898), 29, 54.

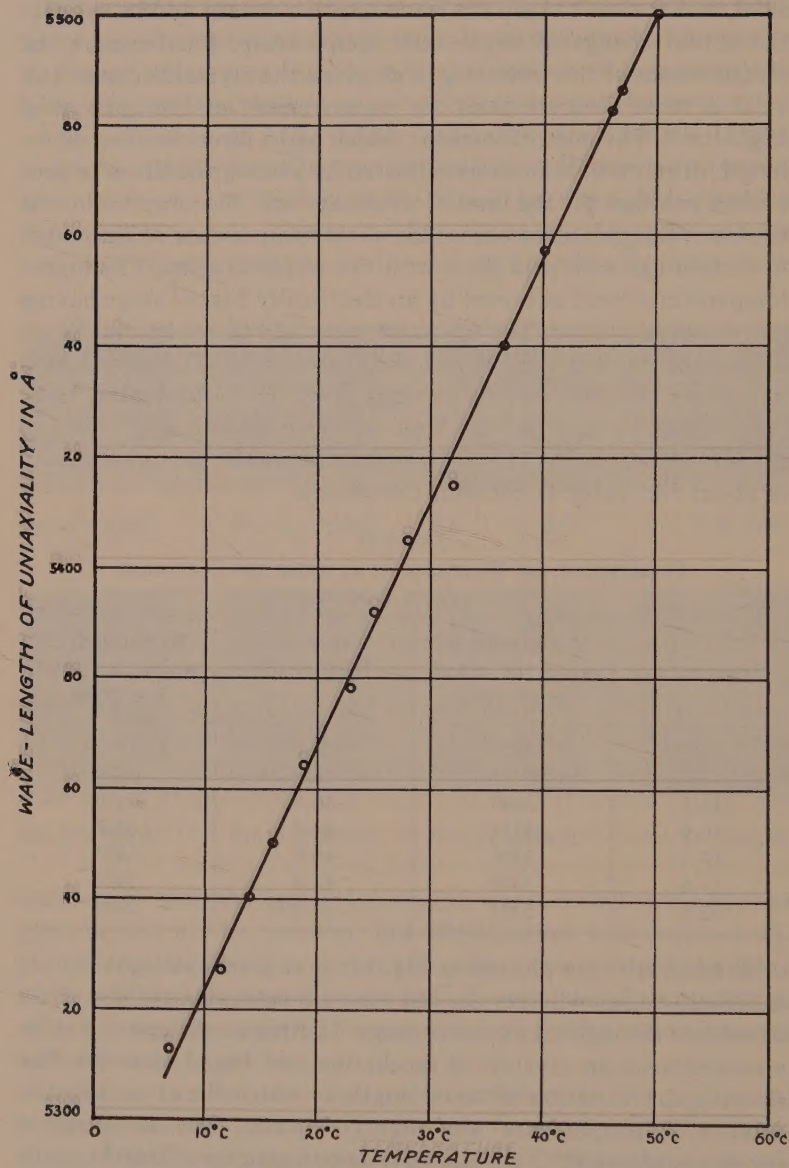


FIG. 12. Variation of Uniaxiality with Temperature.

TABLE III
MEASUREMENTS OF THE SPACE LATTICE AS DERIVED FROM ROTATION PHOTOGRAPHS.

<i>n</i>	Rotation axis [100].		Rotation axis [010].		Rotation axis [001].		Rotation axis [110].		Rotation axis [011].		Rotation axis [101].		Rotation axis [111].	
	μ	<i>I</i>	μ	<i>I</i>	μ	<i>I</i>	μ	<i>I</i>	μ	<i>I</i>	μ	<i>I</i>	μ	<i>I</i>
1	5° 5'	17.39Å	3°56'	22.45Å	9°39'	9.18Å	3°53'	28.50Å	3°45'	24.55Å	4°30'	19.65Å	3°48'	29.10Å
2	10 3	17.24	7 56	22.30	19 7	9.17	7 56	28.05	7 20	24.15	9 9	19.37	7 33	29.35
3	15 45	17.35	12 2	22.18	29 59	9.24	11 48	28.30	11 6	24.05	13 46	19.45	11 20	29.47
4	20 54	17.27	15 58	22.41	41 56	9.22	15 46	28.50	14 51	24.05	18 20	19.57	15 9	29.55
5	26 26	17.26	20 6	22.45			19 56	28.32	18 31	24.20	23 7	19.61	19 1	29.70
6			24 24	22.39			24 1	28.47	22 21	24.30	28 0	19.68		
7			28 47	22.42			28 14	28.56	26 24	24.25	33 12	19.68		
8			33 20	22.45			32 49	28.53						
9			38 7	22.45										
	Mean = 17.31Å		Mean = 22.39Å		Mean = 9.20Å		Mean = 28.44Å		Mean = 24.22Å		Mean = 19.57Å		Mean = 29.43Å	
							$\sqrt{I_{100}^2 + I_{010}^2}$ = 28.30Å		$\sqrt{I_{010}^2 + I_{001}^2}$ = 24.20Å		$\sqrt{I_{100}^2 + I_{001}^2}$ = 19.60Å		$\sqrt{I_{100}^2 + I_{010}^2 + I_{001}^2}$ = 29.76Å	

X-RAY INVESTIGATION

The x -ray study was made by means of rotation and oscillation photographs. The source of the x -rays was a Hadding-Siegbahn tube, which was operated at about 35,000 volts with a tube current of about 25 milliamperes. Photographs were made using the $K\alpha$ radiation from copper and iron anticathodes. Two cylindrical cameras of diameters 57.4 mm. and 114.8 mm. were used.

MEASUREMENT OF IDENTITY PERIODS. Rotation Photographs were made by rotating about the directions [100], [010], [001], [110], [011], [101] and [111]. The values of the identity periods I in these directions were obtained by using the formula:—

$$I = n\lambda / \sin \mu.$$

The angles μ are obtained from measurement of the distances between the "layer lines." The results obtained are shown in Table III. The unit cell has the dimensions

$$I_{100} = 17.31\text{\AA}; I_{010} = 22.39\text{\AA}; I_{001} = 9.20\text{\AA}.$$

These values give an axial ratio:—

$$a:b:c = 0.7743:1:0.4115.$$

The crystallographic axial ratio, which depends on the arbitrary choice of the parametral (111) face, is thus confirmed.

The measurements of the identity periods in the diagonal directions and their comparison with the calculated lengths of the diagonals of the above unit cell show that neither the faces, nor the cell itself, are centered. The space lattice on which the structure is based is therefore the simple orthorhombic lattice Γ_v .

DETERMINATION OF THE SPECIFIC GRAVITY AND THE NUMBER OF MOLECULES IN THE UNIT CELL. An accurate determination of the specific gravity of triphenylbismuthine dichloride, made by means of the pycnometer, gave the following result:—

Sp. gr. of triphenylbismuthine dichloride at $20^\circ/4^\circ = 1.908 = \rho$.
The number of molecules in the unit cell is given by:—

$$N = V / M m_H.$$

where V is the volume of the cell, M the molecular weight of the substance, and m_H the mass of the hydrogen atom. Substituting the appropriate values we get

$$N = \frac{1.908 \times 17.31 \times 22.39 \times 9.20 \times (10^{-8})^3}{511.1 \times 1.65 \times 10^{-24}} = 8.07.$$

There are therefore 8 molecules in the unit cell.

ACCURATE VALUES FOR THE IDENTITY PERIODS OBTAINED FROM THE CONCEPTION OF TOPIC AXES. The measurements of identity periods obtained from rotating crystal photographs are not very accurate; it is usually necessary to carry out more precise measurements. An increase in the accuracy of measurement of rotation photographs has been obtained by G. Hoffmann and H. Mark,⁵ who used a narrow horizontal slit, which makes the "layer lines" become very thin and narrow. Accurate measurements can also be obtained by measuring one of the pinacoid spacings by means of an x-ray spectrometer. In this investigation an x-ray spectrometer was not available. Owing to the closeness of the lines on the rotation photographs very accurate measurements were not obtainable, even by means of the narrow horizontal slit. The conception of topic axes has been familiar to crystallographers for many years. These axes are obtained by considering a volume equal to the molecular volume, associated with a cell, the edges of which stand to one another in the same ratio as the axial ratio. The standard formula for topic axes may easily be applied to calculate the dimensions of the unit cell, by substituting for the molecular volume V the volume V' of unit cell. If there be N molecules of molecular weight M in the cell, then the mass of a unit cell is NMm_H and its volume V' is NMm_H/P . Substituting the values for triphenylbismuthine dichloride we have:

$$V' = \frac{8 \times 511.1 \times 1.65 \times 10^{-24}}{1.908} = 3.530 \times 10^{-21} \text{ ccs.}$$

Knowing the true axial ratios, for which accurate values can be obtained from the ordinary crystallographic axial ratios, and the approximate dimensions of the unit cell got from the rotation photographs, accurate values for $I_{100} = \chi'$, $I_{010} = \psi'$ and $I_{001} = \omega'$ can be calculated.

These calculations give:

$$\begin{aligned} I_{100} = \chi' &= \sqrt[3]{a^2 V' / c} = 17.30 \text{ \AA} \\ I_{010} = \psi' &= \sqrt[3]{V' / ac} = 22.36 \text{ \AA} \\ I_{001} = \omega' &= \sqrt[3]{c^2 V' / a} = 9.14 \text{ \AA}. \end{aligned}$$

DETERMINATION OF THE SPACE GROUP. The spots on the rotation photographs are so numerous that in most cases the "layer-lines" appear as continuous lines; it is therefore impossible to obtain the indices of individual reflecting planes from such photographs.

⁵ *Zeit. f. phys. Chem.* (1924), **111**, 321.

Several oscillation photographs, having an oscillation range of 25° , were made; it was possible to obtain from these photographs the indices of a large number of reflecting planes. Photographs were obtained by oscillation of the face (001) about [110], face (100) about [001] and face (110) about [001]. That these photographs show less spots is due to the fact that only a restricted number of planes come into the reflecting position. It is comparatively easy, by means of the method based on the polar lattice and described by J. D. Bernall,⁶ to find which planes are capable of reflecting. The index of the spot is then easily found by comparing the square of the sine of the measured glancing angle with the squares of the sines of glancing angles of the possible reflecting planes for the particular "layer line." These experimentally found reflecting planes are then examined for missing odd-order spectra, caused by the halving of the planes apparent and dependent on the symmetry of the structure. The following results were found:—

1. Pyramids of the type (hkl). All kinds present, including planes for which ($h+k$), ($k+l$), ($l+h$) or ($h+k+l$) are odd.
2. Prisms of the type (hko). All kinds present, including planes for which h , k , or ($h+k$) are odd.
3. Pinacoids of the type (hoo). Odd orders of reflection occur for the planes (010) and (001), whilst only even orders occur from (100).

The presence of odd order reflections from the various kinds of pyramid faces is merely the result of the underlying space lattice being Γ_v . The space group must therefore, using the notation of Schoenflies, be one of the following:—

$$C_{2v}^1 \text{ to } C_{2v}^{10}, V^1 \text{ to } V^4, V_h^1 \text{ to } V_h^{16}.$$

One should note that in the orthorhombic system the three axial directions are interchangeable and prisms of the type (hko) therefore include (hol) and (okl). The fact that odd order reflections occur from all the kinds of these prisms excludes many of the above space groups. Reference to space group tables⁷ shows that the space group is therefore either:—

$$C_{2v}^1, V^1, V^2, V^3, V^4 \text{ or } V_h^1.$$

The space groups C_{2v}^1 , V^1 and V_h^1 require odd order reflections from all faces; V^2 requires only even orders from one pinacoid; V^3

⁶ *Proc. Roy. Soc.* (1926), **113A**, 117.

⁷ H. Mark. *Die Verwendung der Röntgenstrahlen in Chemie und Technik.*, p. 387.

requires only even orders from two pinacoids; V^4 requires only even orders from the three pinacoids. The occurrence of only even orders from the pinacoid (100) therefore places the structure in the space group V^2 .

The symmetry of this space group V^2 is holoaxial. X-ray evidence is therefore in favor of holoaxial symmetry for the crystals of triphenylbismuthine dichloride.

To bring the crystallographic axes into coincidence with those of the space group, in its usual orientation, a and c must be interchanged. There is also the possibility of interchanging b and the new a axis; no information, however, can be obtained from space group data regarding the relative position of these two axes.

Very little information as to the actual arrangement of the atoms can be obtained from space group considerations. Reference to the tables shows that the most general position in the space group V^2 consists of four equivalent points. Now triphenylbismuthine dichloride contains eight molecules in the unit cell, and it is therefore evident that various atoms of the same chemical element cannot be crystallographically equivalent.

In conclusion I wish to express my gratitude to Dr. Harold L. Alling for the loan of microscopic apparatus and for help in photographing the interference figures. Without his help this part of the investigation could not have been carried out.

ZINC-BEARING CHROMITE

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The October 1929 issue of the *AMERICAN MINERALOGIST* published a paper by L. W. Fisher, entitled "Chromite: Its Mineral and Chemical Composition." On the strength of an extensive study of more than 150 analyses, Fisher distinguishes four chemically different groups which in turn have four subdivisions. Most varieties of chromite can be classed in his groups IIa, IIIa, and IIIc, which have the following chemical compositions:



In his conclusions, Fisher makes the statement that "various members of the spinellid group are isomorphous with each other, but all the members cannot be arranged in a definite isomorphous series," and that "chromite does not contain zinc and cannot be a true variant of a series which contains gahnite."

The writer had the opportunity of making a study of chromite deposits, including a detailed microscopic investigation of various ores from 22 different occurrences from all parts of the world. In two cases, in ore from Ramberget and Värnäs fjeld, near the Island of Hestmandö, Norway, zinc was found as an isomorphous mixture in chromite. This fact is all the more noteworthy as these very occurrences are considered as "standard" types of chromite deposits, in various text books such as Lindgren, Beck, and Beyschlag-Krusch-Vogt. The physical and chemical characteristics of the zinc-bearing chromite are dealt with in detail in the following paragraphs.

Macroscopically the color of the ore is much like that of ordinary chromite, its luster, however, being considerably higher. The mineral has no cleavage. The streak is blackish-brown, being obviously different from that of pure chromite. The hardness varies from 6 to 7; the specific gravity was found to be 4.5. The magnetic properties of the ore are remarkable; even small particles show polar magnetism.

Studies of thin sections and polished sections of zinc-bearing chromite afford the observation of more distinguishing features.

Polished sections of ore from Hestmandö were remarkably easy to make, and a good polished surface was obtained after sufficient preliminary grinding with very fine emery. On the polished section the color of the ore is like that of ordinary chromite and no difference could be found after various etching tests. Polarized light, however, is affected by the mineral, causing anisotropism, although only to a slight degree. This is the most remarkable point of difference for distinguishing zinc-bearing from ordinary chromite. In thin sections the mineral is absolutely opaque, even in exceedingly thin slides, which is another distinguishing feature.

These physical properties (streak, color, hardness, optical behavior), being different from those of ordinary chromite, induced the writer to obtain a complete chemical analysis of the ore.

The material for the analysis was carefully selected ore from the occurrence at Ramberget. Two thin sections and two polished sections were prepared from the specimen used for the analysis, as a check on the homogeneous character of the ore. These sections showed all the above mentioned physical properties.

Minute inclusions of some silicate were detected in the ore, varying in size from 3 to 60 microns, the average being between 10 and 20 microns. These particles consisted of olivine and a very little plagioclase. The carefully powdered ore was separated from the small amount of silicate by means of a magnet. Although this method afforded a fairly clean separation, it was impossible to remove all silicate grains intergrown with ore of an approximate size of less than 10 microns. Experiments attempting to remove these traces of silicates by means of centrifugal force were unsuccessful on account of the minute size of the inclusions.

The results of the chemical analyses of the ore, prepared as described above, were as follows:

	Analysis I Per cent	Analysis II Per cent
Fe ₂ O ₃	50.49	50.28
Cr ₂ O ₃	41.48	41.84
Al ₂ O ₃	0.35	0.76
MnO	Trace	Trace
NiO	Trace	Trace
MgO	4.68	4.88
ZnO	2.62	2.21
SiO ₂	1.74	1.45
	101.36	101.42

In order to facilitate a comparison of the results, the values of the analyses were calculated as spinellid components. The silica was accounted for as contained in olivine. The value for $\text{FeO} \cdot \text{Fe}_2\text{O}_3$ may not be quite accurate, as FeO was not determined in the analyses. Thus a possible isomorphous admixture of Fe_2O_3 may have escaped the computation.

In the following are the values calculated from analysis II:

61.61%	$\text{FeO} \cdot \text{Cr}_2\text{O}_3$
18.62%	$\text{MgO} \cdot \text{Fe}_2\text{O}_3$
8.48%	$\text{FeO} \cdot \text{Fe}_2\text{O}_3$
6.55%	$\text{ZnO} \cdot \text{Fe}_2\text{O}_3$
1.06%	$\text{MgO} \cdot \text{Al}_2\text{O}_3$
2.39%	Olivine
<hr/>	
98.71%	

In order to obtain values for the zinc-bearing chromite free of silicates, the latter were computed as $(\text{Mg}_2\text{SiO}_4)_{90} \cdot (\text{Fe}_2\text{SiO}_4)_{10}$, and percentage values were calculated for the pure ore:

63.96%	$\text{FeO} \cdot \text{Cr}_2\text{O}_3$
19.33%	$\text{MgO} \cdot \text{Fe}_2\text{O}_3$
8.80%	$\text{FeO} \cdot \text{Fe}_2\text{O}_3$
6.81%	$\text{ZnO} \cdot \text{Fe}_2\text{O}_3$
1.10%	$\text{MgO} \cdot \text{Al}_2\text{O}_3$
<hr/>	
100.00%	

The above analysis classes the Hestmandö ore with the members of the spinellid group, belonging to the subdivision of the chromium spinels on account of the high content of Cr_2O_3 .

It is distinguished from ordinary chromite by a considerable admixture of MgO, ZnO, Al_2O_3 and Fe_2O_3 . The presence of ZnO as an isomorphous admixture in the subdivisions of chromium spinels is entirely new.

Since it is known that compounds of the structure of the spinellid group may be dimorphous, an *x*-ray investigation became necessary to explain the optical behavior of the mineral.

The *x*-ray photograph was taken after the method of Debye-Scherrer, with a revolving camera of 5.7 cm. diameter. For reference an *x*-ray picture was also taken of a pulverized single chromite crystal from Svilare, near Ueskub, Macedonia.

The results, given by the number and the intensity of the lines, were as follows:

ORE FROM RAMBERGET, HESTMANDÖ

Time of exposure

2160 milliamperes-minutes

Angle of reflection	Intensity
19°21'	medium to weak
20°42'	medium to weak
22°54'	strong
25°00'	weak
27°48'	medium
33° 9'	medium
34°12'	medium
36°36'	medium
37° 6'	strong
41°00'	strong
49°21'	very weak
54°27'	very weak
62°42'	very strong
67°42'	strong

CHROMITE FROM SVILARE

Time of exposure

2250 milliamperes-minutes

Angle of reflection	Intensity
20°30'	weak
23°00'	strong
25°30'	very weak
28°00'	weak
33°00'	weak
37°36'	medium
41°30'	strong
63°54'	strong
69° 6'	strong

The photographs show the same isometric lattice in both ores. The larger angle of reflection of the Svilare ore, compared with the Ramberget ore, indicates a distinct change of the parameter.

Summarizing the results of the investigation of the chromite from Ramberget, we may characterize the ore as a new member of the chromite group, distinguished by a high percentage of Cr_2O_3 and a noticeable isomorphous admixture of MgO , FeO , ZnO , and Fe_2O_3 . The x -ray investigation showed an isometric lattice. Thus the anisotropism of the mineral has to be accounted for as an optical anomaly, due to the isomorphous admixtures, causing irregularities in the fine structure of the mineral.

ON THE TRICLINIC MANGANIFEROUS PYROXENES

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(Continued from page 429)

MINERAL DESCRIPTIONS

RHODONITES

The following rhodonites have been examined optically and chemically: rhodonite from Vittinge in Finland, rhodonite from Harstigen and three specimens of rhodonite from Långban. Also optical determinations have been made on three other specimens from Sweden, one from Långban and two from Dalsland. The specimens studied comprise mixtures of 70–95 mol. per cent of MnO.

RHODONITE FROM VITTINGE

A description of the mineral deposit at Vittinge was published by M. Saxén²⁹ several years ago. According to him the rhodonites of this occurrence show some variations as to color, some species being light red, while others are more brownish. This depends on the amount of iron, the FeO-content in three determinations varying from 0.27 to 3.70 per cent by weight. An analysis of the brownish-colored variety gave the following result (analysis by N. Sahlbom):

SiO ₂	46.57	MnO	46.28
TiO ₂	0.00	CaO	1.60
Al ₂ O ₃	0.73	MgO	0.12
FeO	3.70	H ₂ O	0.72
			99.72

The refraction was shown to be raised by the presence of FeO as follows:

FeO%	0.27	1.58	3.70
β_{Na}	1.729	1.729	1.734

The determinations referred to in the following were made on a specimen from the collections of the State Museum (RM. No. 6296). The specimen is composed of a granular aggregate of rose-

²⁹ *Fennia* 45 (No. 11), 1925, p. 15.

colored rhodonite and quartz. As no other minerals are present and the rhodonite holds only a few inclusions of quartz, it was easy to obtain it in a pure state. The separation was made with the aid of Clerici's solution. On account of the granular character measurements of the refraction on a total refractometer were not possible. The values of α and γ obtained on the powder by means of the immersion method were 1.733 and 1.747. The double refraction is 0.014. A direct measurement of $\gamma - \alpha$ and $\beta - \alpha$ gave as a result 0.014 and 0.004. Thus β can be calculated as 1.737. The measurement of $2V_\gamma$ on a universal stage gave as an average reading $61^\circ (\pm 0.5^\circ)$.³⁰ If we calculate $2V_\gamma$ from the indices, we get the value $64^\circ 44'$. This implies an error of about 0.001 in the determinations of the indices and the double refraction.

The analysis made by Dr. A. Bygdén is given as No. 1 in Table 1. In slides the rhodonite shows thin twinning lamellae parallel to (010). The mineral is clear and free from traces of deformation. Readings were obtained on sections cut at suitable angles to the chief cleavages and the γ bisectrix. The resulting positions are shown in the stereographic diagram of Fig. 8, where all corresponding determinations on the minerals studied are collected. The average values obtained from five measurements are quoted below. As $\phi = 0$, the cleavage plane ($\bar{1}10$) is accepted.

	($\bar{1}10$):($\bar{1}\bar{1}0$)	α	β	γ	(0 $\bar{1}0$) ^a
ϕ	$92^\circ 44'$	$43.9^\circ (\pm 1.6^\circ)$	$312.6^\circ (\pm 0.9^\circ)$	$140.9^\circ (\pm 5.1^\circ)$	$137.8^\circ (\pm 0.3^\circ)$
ρ	90°	$86.3^\circ (\pm 1.1^\circ)$	$65.3^\circ (\pm 0.9^\circ)$	$25.2^\circ (\pm 1.2^\circ)$	90°

^a According to measurements on twinning lamellae.

The cleavage angle was measured on a goniometer on cleavage prisms. On account of the small size of the prisms the value given above is only approximate, within the limit of about $20'$. The spec. gravity, found by using the floating method and the Westphal balance is 3.70.

RHODONITE FROM HARSTIGEN

The sample received from Prof. Hamberg consisted of two transparent crystals of a maximum size of 8–10 mm. According to Ham-

³⁰ The figures within parentheses indicate the greatest difference between the average values and the separate measurements.

berg the crystals belong to his type *a c r k*. The corresponding analysis, therefore, is No. 4 (anal. G. Paykull³¹). This analysis is quoted as No. 2 in Table 1. Moreover all analyses made on the Harstigen rhodonite are very similar, only the iron-content in some cases is a little higher than in the analysis quoted here. A polished artificial facet on one of the crystals gave distinct lines of total reflection. The following values were recorded: $\alpha=1.7208$, $\beta=1.7251$, $\gamma=1.7326$. The corresponding calculated angle for $2V_\gamma$ is 74.3° .

The preparation of slides from the crystals offered difficulties on account of the splitting up of the mineral along the cleavages. It was necessary to melt fragments in glass and cut the melt. But a close orientation of the slides was rendered impossible and on account of this difficulty no slide perpendicular to γ was obtained. The measurements of the axial angle, therefore, had to be made on the bisectrix α , only one of the optic axes being accessible. The average of six measurements gave as a result $V_\alpha=52.5^\circ \pm 1^\circ$, and from this $2V_\gamma$ becomes 75.8° .

As a control the refraction was determined on another crystal, taken from the collections of the State Museum (RM. No. 13360). The crystal belongs to the type *c k r d* of Hamberg and the corresponding analysis No. 2 of Hamberg's table is almost identical with that quoted by me. On this crystal a measurement of the dispersion also was made.

		α	β	γ	$2V_\gamma$ calc.
red	(656.3 $\mu\mu$)	1.7183	1.7226	1.7302	$74^\circ 22'$
yellow	(Na light)	1.7206	1.7249	1.7324	$74^\circ 34'$
green	(485.15 $\mu\mu$)	1.7337	1.7383	1.7458	$75^\circ 58'$

G. Flink, *loc. cit.*, determined the axial angle of the Harstigen rhodonite as $75^\circ 57'$ for red (Li), $76^\circ 12'$ for yellow (Na), and $76^\circ 22'$ for green (Tl). The axial angle for yellow was found by Des Cloizeaux as $75^\circ 4'$.

The cleavage angle is given by Flink as $92^\circ 29'$, by Hamberg as $92^\circ 21' - 92^\circ 23'$. On fragments of the crystals I found angles of $92^\circ 13' - 92^\circ 37'$ and as an average $92^\circ 25'$. The spec. gravity was determined by Dr. Bygdén by weighing in air and in water, and by the floating method. The resulting average was 3.616.

The following coordinates for the optical orientation are the averages from seven measurements on sections cut obliquely to the cleavages:

³¹ *Op. cit.*, p. 572, 1891.

	(110):(110)	α	β	γ
ϕ	92°25' ^a	40.2° ($\pm 2.6^\circ$)	303.7° ($\pm 3.7^\circ$)	143.3° ($\pm 2.9^\circ$)
ρ	90°	80.3° ($\pm 1.7^\circ$)	56.6° ($\pm 3.6^\circ$)	35.8° ($\pm 3^\circ$)

^a According to goniometrical measurements.

A more complete examination of the Harstigen rhodonite has also been made by Hey. The values found by him on the whole agree well with those of the present writer. He found: $\alpha = 1.720$, $\beta = 1.725$, $\gamma = 1.733$, $2V_\gamma = 75^\circ$, spec. gravity = 3.615.

RHODONITE FROM LÅNGBAN—SPECIMEN 1

The specimen examined (RM.13448) consisted of crystals of a thick tabular habit which had grown from a granular aggregate of rhodonite and small grains of a brownish mineral, which was not studied in detail. The size of the crystals varied from 3–10 mm. in the longest dimension. For the investigation only the tabular crystals were used. This rhodonite evidently was the first instance showing that the properties of rhodonites and those of bustamites do not vary according to the relations of an isomorphic mix-series. This was shown when an analysis had been made of the crystals. To exclude the possibility that a zonal structure or the presence of impurities might have influenced the positions of the corresponding points in the diagrams a second analysis was made by Dr. Bygdén. For this analysis the crystals were powdered and the powder was carefully treated with Clerici's solution. A few small grains of the brownish mineral were thereby removed. The spec. gravity determined on the powder by the floating method was 3.573. On the crystals first analyzed determinations by weighing in air and water, and by the floating method had given a similar result of 3.575. Both the analyses are quoted in Table 1 as Nos. 3 and 4, the former referring to the analysis first made, the latter to the second. As may be seen from the table, the purifying of the powder has exercised a sensible, though not great, effect on the values recorded. For the point in question whether rhodonites and bustamites belong to an isomorphous series or not, the differences in the two analyses are of no importance.

On polished facets on two of the crystals the following values of the refraction were recorded:

	α	β	γ	$2V_\gamma$ calc.
1.	1.7132	1.7171	1.7260	67.5°
2.	1.7130	1.7171	1.7259	69.2°

The average value of the axial angle becomes 68.4°. The average of six measurements of V_α in slides cut nearly perpendicular to α (only one axis was accessible) was 56°. From this $2V_\gamma$ becomes 68° ($\pm 0.7^\circ$). In this case also fragments of the crystals had to be melted in glass and no section with both axes accessible was obtained.

Besides isolated small inclusions of the brownish mineral (scheffelite?) the rhodonite contains quite small lamellar inclusions of diopside arranged in the manner described in the general discussion. The number of the lamellae is somewhat variable, but in general they are not numerous and the inclusions would easily escape attention if they are not seen in sections parallel to (001).

The coordinates of the bisectrices resulting from four measurements on two sections are as follows:

	($\bar{1}10$):($\bar{1}\bar{1}0$)	α	β	γ	($0\bar{1}0$) ^b
ϕ	92°13' ^a	38.5° ($\pm 1.2^\circ$)	298.2° ($\pm 1.5^\circ$)	143.2° ($\pm 1.6^\circ$)	136.7°
ρ	90°	77.5° ($\pm 0.9^\circ$)	52.3° ($\pm 1.3^\circ$)	40.6° ($\pm 1.2^\circ$)	90°

^a From goniometrical measurements.

^b According to one measurement on twinning lamellae.

RHODONITE FROM LÅNGBAN—SPECIMEN 2

The appearance of this rhodonite is similar to that of the preceding one. A part of a larger crystal was used for the determinations. The specimen used belongs to the collections of the State Museum (RM. 13448). When studying slides of the crystal selected it was shown that this rhodonite was less homogeneous than Specimen 1, and that it contained a considerably larger number of "perthitic" inclusions of diopside. In addition to this there occur small grains of the same mineral which are not uniformly oriented, and not homoaxial intergrown with the rhodonite. On these grains $\gamma-\alpha$ was determined as 0.029 and the axial angle as about 55°. The refraction is somewhat lower than for the rhodonite. The same cleavages are seen as in the rhodonite. These properties agree with those of diopside. A conspicuous feature is that the perthitic in-

clusions are very richly distributed along irregular, fissure-like streams in the rhodonite. Also, on the whole, the amount of the perthitic diopside varies, some parts of the rhodonite being clearer and almost free from inclusions, other parts being clouded by them. Figs. 5 and 6 show two reproductions from parts of the slides that are rich in diopside.

Besides diopside there are present several small grains of a colorless undeterminable mineral (amphibole?, optically neg., $2 V_{\alpha}$ large).

Before making the analysis the powdered rhodonite was treated with Clerici's solution, the limits of the gravity of the solution being kept as near to that of the rhodonite as possible. In this way a homogeneous powder was obtained which would be practically free from the diopside grains but not free from all perthitic inclusions, the greater part of which may be included in the analysis. Their amount, on an average, is probably about 2–3 vol. per cent. The analysis made by Dr. Bygdén is quoted as No. 6 in Table 1.

The refraction measured on a polished plate, taken from the crystal analyzed, gave as a result: $\alpha = 1.7112$, $\beta = 1.7153$, $\gamma = 1.7239$. The corresponding calculated angle for $2 V_{\gamma}$ is 69.5° . Direct measurements on V_{α} (only one axis was accessible) had shown it to be 55.8° ; $2 V_{\gamma}$ calculated therefrom was 68.4° . The spec. gravity determined by the floating method was 3.563.

Measurements on the optical orientation showed it to be similar to that of specimen No. 1 from Långban. In the slides twinning lamellae parallel to (010) are visible.

RHODONITE FROM LÅNGBAN—SPECIMEN 3

This specimen was kindly sent, at the request of the present writer, from the Mineral Department of the British Museum by Dr. M. H. Hey. It is the same specimen (BM. 43473) which had been examined before by that writer, who had studied the bustamite associated with the rhodonite. The specimen consisted of a cleavage piece about 2 by 3 cm. in size. When examined in a slide, it was found to be rather nonhomogeneous. The dominant mineral is rhodonite, but included in it are the following minerals: bustamite, calcite, quartz, some micaceous pseudomorphous substance, and a small amount of the usual perthitic diopsodic inclusions. The bustamite is intergrown with the rhodonite, the different patches of the former present in the slide showing the same optical orienta-

tion, but this orientation does not agree with that of the rhodonite. The axes of the cleavage zone of both minerals form an angle of about 20° with each other. Furthermore, the obtuse cleavage angle of the bustamite runs in the same direction as the acute angle of the rhodonite. To judge from the description by Hey it is probable that the material of the bustamite, picked out by him from a crushed part of the specimen, may have come from some larger homogeneous masses of bustamite. In the material studied by me the quantity of bustamite was subordinate. At a preliminary separation of the minerals there was obtained 0.175 grams bustamite, 0.493 grams rhodonite and 0.078 grams quartz; calcite and micaceous pseudomorphs. These figures give an approximate idea of the relative amounts of the minerals contained in the specimen. From the powder the calcite was dissolved by hydrochloric acid and then the rhodonite was purified in the usual way. It could be obtained practically pure, the only impurities visible in the powder being small perthitic inclusions of diopside. The analysis made by Dr. Bygdén is quoted as No. 5 in Table 1. It corresponds to the highest Ca-bearing member of the rhodonite series found by me, and on account of the paragenesis with the bustamite it is not probable that varieties with any considerably greater amount of CaO exist, unless MgO should be completely replaced by CaO.

On a polished facet of the specimen the following values of the indices were recorded: $\alpha=1.7157$, $\beta=1.7203$, $\gamma=1.7281$. From this $2 V_\gamma$ becomes 75.7° . From direct measurements on V_α the value 74° is obtained for $2 V_\gamma$. The spec. gravity of the powder was determined by the floating method as 3.581.

On grains melted in glass and cut obliquely to the cleavages, as on slides about perpendicular to α , the optical orientation was found to be about identical with that of the two preceding specimens from Långban. The angle of the cleavages, according to goniometrical measurements, is $92^\circ 24'$.

OPTICAL DETERMINATIONS ON OTHER RHODONITES

In connection with the researches summarized above, measurements of the refraction were made on rhodonite from Långban (RM. 13584), from Klapperud, Dalsland (RM. 13260) and from Kesebol, Fröskog, Dalsland (RM. 280181). The first-named specimen consisted of large anhedral rhodonite individuals occurring together with thaumasite and several other minerals, not deter-

mined; the second was a fairly large homogeneous cleavage mass; and the third consisted of crystals grown in a fissure, filled with quartz. The determinations were made on a total refractometer and the values recorded are the following:

	α	β	γ	$2V_{\gamma}$ calc.
Långban	1.7158	1.7199	1.7284	70.2°
Klapperud	1.7167	1.7215	1.7298	74.6°
Kesebol	1.7171	1.7221	1.7299	77.7°

All these values correspond to mixtures of from 22–25 mol. per cent of Ca (Mg) SiO₃ (see diagram in Fig. 10).

BUSTAMITES

The bustamites can be distinguished macroscopically from the rhodonites by a more intense pink color and by its fibrous and radiating structure, which is due to the better development in this mineral group of the cleavage parallel to (010). The material studied and reported in this paper comprises four specimens, three from Långban and one from Franklin Furnace. Also determinations of the axial angle was undertaken on a series of specimens from the same localities.

BUSTAMITE FROM LÅNGBAN—SPECIMEN 1

The analysis corresponding to this specimen was originally made for the State Museum by its chemist R. Blix and was kindly placed at the disposal of the present writer. It is quoted as No. 7 in Table 1. According to the analysis this bustamite is the richest Ca-bearing bustamite studied by me, the molecular ratios of CaO: Mn(Mg)O being nearly 1:1. In the specimen the bustamite is associated with a brownish mineral, showing the same cleavage as a pyroxene (probably schefferite). The bustamite forms a granular aggregate, but homogeneous individuals were obtained of a size sufficient to permit measurements on a total refractometer.

The following values were recorded:³²

		α	β	γ	$2V_{\alpha}$ calc.
Red	(656.3 μ)	1.66977	1.68280	1.68458	40°28'
Yellow	(Na-light)	1.67198	1.68493	1.68670	40°56'
Green	(485.15 μ)	1.68342	1.69648	1.69856	43°12'

³² In the case of axial angles of the small size occurring in the bustamites a change even in the fourth decimal place produces a considerable effect on the calculated angle. On this account the original values obtained through measurements are quoted unreduced.

Thus the dispersion is of about the same order as in the rhodonites. The axial angles resulting from direct measurements on a universal stage are as follows: red = 40.2° , yellow = 40.5° , green = 43° .

On a bustamite from Långban, Des Cloiseaux found the following axial angles: 2 E , red = 68° , green = 72° . When using the β -values quoted above, we get 2 $V_a = 38^\circ 46'$ and $40^\circ 32'$. It remains undecided, however, whether the specimen used is of the same composition as specimen 1 or of one of the specimens to be described later.

In slides the ordinary cleavages are visible but the cleavage parallel to (010) is better developed than in the rhodonites. No twinning lamellae are seen parallel to the face named but parallel to (110) simple twinning is common. On the powder of the analyzed specimen I found the spec. gravity to be 3.317.

The average coordinates of the bisectrices according to six measurements on different grains are given below. The position of (0 $\bar{1}$ 0) is the result of two measurements on the universal stage, the angle of the cleavages was determined from measurements on a goniometer.

	(110):(1 $\bar{1}$ 0)	α	β	γ	(0 $\bar{1}$ 0)
ϕ	$94^\circ 35'$	$44.0^\circ (\pm 1.8^\circ)$	$308.8^\circ (\pm 4^\circ)$	$143.9^\circ (\pm 3.9^\circ)$	$140.2^\circ (\pm 0.4^\circ)$
ρ	90°	$82.2^\circ (\pm 3.2^\circ)$	$53.8^\circ (\pm 3.2^\circ)$	$36.8^\circ (\pm 3.8^\circ)$	90°

BUSTAMITE FROM LÅNGBAN—SPECIMEN 2

This specimen of bustamite had been analyzed previously by G. Lindström (RM. 13397).³³ His analysis is quoted as No. 8 in Table 1. According to the analysis this specimen is considerably richer in MnO and poorer in CaO than the preceding one. Otherwise the chemical differences are small. On a larger individual of the original specimen the following values were obtained on the refractometer: $\alpha = 1.68153$, $\beta = 1.69487$, $\gamma = 1.69691$. The axial angle calculated from the indices is $42^\circ 54'$. On the powder of the bustamite the angle was measured as 43.3° . For the spec. gravity I obtained by the floatation method the value of 3.386. Lindström's value is 3.40.

The coordinates resulting from two measurements are given below. The cleavage angle is determined by goniometrical measure-

³³ *Kungl. Vet. Akad. Övers*, 1880, 53.

ments. On account of the somewhat deformed condition of the grains the value recorded is only approximate.

	(I10):(II0)	α	β	γ
ϕ	95°22'	43.7° ($\pm 0^\circ$)	311.8° ($\pm 0.2^\circ$)	142.5° ($\pm 4.7^\circ$)
ρ	90°	86.6° ($\pm 0^\circ$)	70.2° ($\pm 5.6^\circ$)	20° ($\pm 5.5^\circ$)

BUSTAMITE FROM LÂNGBAN—SPECIMEN 3

The specimen is that from which the rhodonite from Långban, spec. 3, was separated (BM. 43473). Of the bustamite associated with the rhodonite only a small quantity (0.23 g) was obtained practically pure. The impurities present were a few small remnants of rhodonite adhering to the bustamite. The spec. gravity of the powder was 3.410. The corresponding analysis by Dr. Bygdén is No. 9 in Table 1.

An analysis of bustamite had been made previously by Hey. The values found by him are given below under column 2. They agree rather well with those of Bygdén, which are quoted under 1. The greatest difference is to be found in MgO, the amount of which is very small in the analysis by Hey. The difference between the values of this oxide in the two analyses corresponds approximately to the deficiency in the total sum of the analysis by Hey. Hence it seems probable that the value for MgO in his analysis is too low.

	1	2
SiO ₂	48.31	47.69
Al ₂ O ₃	tr.	0.43
Fe ₂ O ₃		0.05
FeO	1.87 ^a	1.93
MnO	33.04	32.93
MgO	1.90	0.02
CaO	14.93	15.24
Ign. loss		0.29
	100.05	98.65 ^b

^a Determined as Fe₂O₃.

^b In the sum 0.07 ZnO is included.

The refraction of the bustamite could not be determined by the total reflection method. By immersion γ was found to be 1.7029. In a slide nearly perpendicular to β the double refraction $\gamma - \alpha$ was measured as 0.015–0.016. From this α becomes 1.6874 and from the measured axial angle β has been calculated as 1.7014. The axial

angle $2V_\alpha$ recorded in the slides was 36.2° . On a fairly large inclusion in the rhodonite the angle of the cleavages was goniometrically measured as approximately $94^\circ 57'$.

In order to obtain sections suitable for measurements of the optical orientation the powder was melted in glass and cut. The coordinates of the bisectrices resulting from three measurements are given below:

	(I10):(I10)	α	β	γ
ϕ	$94^\circ 57'$	$46.5^\circ (\pm 2.7^\circ)$	$316.3^\circ (\pm 1.1^\circ)$	$144.1^\circ (\pm 2.1^\circ)$
ρ	90°	$87.9^\circ (\pm 0.1^\circ)$	$76.8^\circ (\pm 3^\circ)$	$13.1^\circ (\pm 2.8^\circ)$

The values of the optical properties recorded by Hey are the following: $\alpha = 1.695$, $\beta = 1.703$, $\gamma = 1.710$; $2V_\alpha$ approximately $= 84^\circ$,³⁴ spec. gravity = 3.418.

BUSTAMITE FROM FRANKLIN FURNACE

The specimen (RM. No. 24301) studied consisted of a coarse granular aggregate of bustamite, white or feebly yellowish-white willemite and franklinite. The bustamite was picked out by hand in ultraviolet light. Though great care was taken, small inclusions of willemite remained in the resulting powder. The small content of ZnO shown in the analysis may, therefore, at least be partly caused by them. The spec. gravity of the powder was found to be 3.324. The resulting analysis, made by Dr. G. Assarsson, is quoted as No. 10 in Table 1.

On the total refractometer the indices of refraction were measured as: $\alpha = 1.67493$, $\beta = 1.68766$, $\gamma = 1.68973$. $2V_\alpha$ calc. from the indices is $43^\circ 32'$. The angle directly measured is $44.6^\circ (\pm 0.3^\circ)$. The average coordinates resulting from three measurements on different grains are:

	(I10):(I10)	α	β	γ	(0I0)
ϕ	$95^\circ 11'$ ^a	$44.1^\circ (\pm 1.8^\circ)$	$310.1^\circ (\pm 1.5^\circ)$	$143.3^\circ (\pm 2.9^\circ)$	$140.2^\circ (\pm 0.8^\circ)$
ρ	90°	$83.8^\circ (\pm 0.8^\circ)$	$57.7^\circ (\pm 1.8^\circ)$	$33.2^\circ (\pm 2.^\circ)$	90°

^a According to goniometric measurements.

³⁴ This angle was not measured directly, but it was obtained by construction. According to a personal letter from Dr. Hey a mistake with an angle was made in the construction. If the correct angle is used the result will agree with that of the present writer.

In the slides simple twinning is seen parallel to $(1\bar{1}0)$. Thus the twinning face is not the same as in the first described bustamite from Långban, but otherwise both the optical and the chemical properties are similar to those found on that specimen.

The bustamite from Franklin Furnace has been studied chemically and optically by E. S. Larsen and E. V. Shannon³⁵ and by M. H. Hey. The analyses indicate only small variations in the chemical composition. The content of ZnO in the analyses may, for the most part, arise from inclusions of willemite. The optical data given by the writers named show some departures from the values recorded by me. The figures given by the former and those found by me are compared below.

Mol. per cent										
	MnSiO ₃	FeSiO ₃	MgSiO ₃	CaSiO ₃	Sp. gr.	α	β	γ	$2V_{\gamma}$	$m:M$
Larsen and Shannon	43.01	0.45	1.96	54.58	—	1.662	1.674	1.676	44° ($\pm 3^\circ$)	94°55'
Hey	46.65	0.09	0.08	53.19	3.302	1.664	1.675	1.679	50–55°	95°13'
Sundius	49.23	0.61	1.54	48.62	3.324	1.67493	1.68766	1.68973	44.1° ^a	95°11'

^a The mean of the calculated and the measured angles.

The axial angles calculated from the indices, as determined by the two first named writers, are 43°38' and 62°2'. In both cases the refraction seems to have been determined by the immersion method.

THE AXIAL ANGLES OF OTHER BUSTAMITES FROM LÅNGBAN AND FRANKLIN FURNACE

The survey of the axial angle of bustamites is rather easy to make on the powder of the mineral embedded in Canada balsam, because bustamites are negative with a small axial angle and α is directed nearly perpendicularly to the axis of the cleavages. Most of the specimens from Långban present in the collection of the State Museum were investigated in this way. Only in two cases were ordinary slides made. In all cases I obtained axial angles around 40°–44°. On one specimen from Franklin Furnace with an angle of 44.7° the orientation of the bisectrices was measured and found to be similar to that of the sample analyzed from this locality.

From this survey it appears that the axial angle of the bustamites

³⁵ *Am. Mineralogist*, 1922, vol. 7, p. 95.

shows only small variations. Probably, therefore, the value 50°–55° found by one of the writers cited above may be due to some error.

IRON RHODONITES AND SOBRALITE

The rhodonites proper and the bustamites are characteristic minerals of the oxidized Mn-ores which are associated with oxidized iron-ores but are poor in ferrous iron. The Fe-rich varieties of the rhodonite group, here named iron rhodonite and sobralite, on the other hand, accompany eulysitic skarn ores, composed of minerals rich in ferrous silicates as knebelitic olivine, spessartite, and hedenbergitic pyroxene. Mineral occurrences of this kind containing triclinic pyroxenes of the species named are to be found at V. Silvberg, Tunaberg and Tuna Hästberg, all located in the central and southern parts of Sweden. A rhodonite with more moderate amounts of FeO is known from Gåsborn in central Sweden. The relations of the corresponding ore occurrences are more doubtful and not yet well understood. From South Carolina, North America, a triclinic mineral, chemically related to sobralite, has been described under the name of pyroxmangite,³⁶ but the information about it is still incomplete.

IRON RHODONITE FROM GASBORN

The mines of Gåsborn have recently been described briefly by N. H. Magnusson.³⁷ The rhodonite was known previously through a note by J. L. Igelström, who has published an analysis of a specimen from the Stålmalms mine.³⁸ As the amount of Fe₃O₄ present as included magnetite was not determined by him, a new analysis was necessary, and this was performed by G. Assarsson (No. 11 in Table 1). The specimen analyzed (RM. No. 171773) is made up of a very coarse aggregate of a black rhodonite, the individuals of which attain a size up to 5 cm. The black color is caused by numerous small inclusions of magnetite. A part of the magnetite was drawn out from the powdered material by a magnet, but the greater part could not be removed. The amount of Fe₃O₄ in the material analyzed is, calculated from the value of Fe₂O₃, 4.54 per cent by weight. Besides the rhodonite contains small inclusions of quartz, which calculated from the excess of SiO₂ is 1.74%. In addition

³⁶ W. E. Ford and W. M. Bradley, *Amer. Journ. Sc.*, Ser. 4, Vol. 36, p. 169, 1913.

³⁷ *S.G.U., Ser. Ca*, No. 23, p. 98.

³⁸ *K.V.A. Övers.*, Bd. 40, No. 7, p. 91, 1883.

to these impurities very small inclusions of a colorless or feebly green amphibole (tremolite?) are present. The amount of this material can not be calculated, but its quantity is small, and its influence must be inconsiderable. The iron content of the rhodonite is 5.2 per cent by weight (9.27 mol. per cent).

In slides the inclusions of magnetite are seen to be arranged in a peculiar manner along planes parallel to (010). The usual cleavages according to (110) and ($\bar{1}\bar{1}$ 0) are well developed. Thin twinning lamellae parallel to (010) occur locally. In addition a coarse intergrowth of lamellar individuals is developed in such a manner that the lamellae are turned 180° to each other around an axis perpendicular to (010), but the lamellae bound each other along planes parallel to (001). The twinning movement accordingly is the same as in the usual thin lamellae parallel to (010), but the planes of contact are different. Through the twinning movement β and γ of the one individual are brought to a nearly parallel position with γ and β of the other, whereas the directions of α of both individuals form a small angle with each other. The lamellae of this type are sometimes very broad (up to 2 cm.), and more irregular intergrowths of the individuals can also be seen along the contacts.

On a polished plate without visible twinning lamellae the refractive indices were determined as: $\alpha = 1.7205$, $\beta = 1.7251$, $\gamma = 1.7326$. $2V_\gamma$ from these values was found to be 76° . Direct measurements gave $76.8^\circ (\pm 0.3^\circ)$. On account of the inclusions no reliable value of the spec. gravity could be obtained.

The coordinates of the bisectrices resulting from four measurements are as follows:

	($\bar{1}$ 10):($\bar{1}\bar{1}$ 0)	α	β	γ	twinning lamellae (010)
ϕ	$92^\circ 24'$ ^a	$41.5^\circ (\pm 4.3^\circ)$	$296.2^\circ (\pm 4.8^\circ)$	$145.7^\circ (\pm 1.7^\circ)$	137.0° ^b
ρ	90°	$74.3^\circ (\pm 2.5^\circ)$	$45.9^\circ (\pm 4.3^\circ)$	$47.6^\circ (\pm 3.7^\circ)$	90°

^a According to goniometrical measurements.

^b One measurement.

IRON RHODONITE FROM TUNA HÄSTBERG

This rhodonite has recently been described by the present writer,³⁹ and only a summary of the results will be quoted here.

³⁹ *Geol. Fören. Förhandl.*, Stockholm, Bd. 52, p. 403.

The corresponding analysis is No. 12 in Table 1. It shows a content of FeO of 14.51 per cent by weight corresponding to 26.03 mol. per cent. Notwithstanding this the mineral has maintained the optical properties of a rhodonite with small modifications. The refractive indices resulting from measurements by the immersion method are: $\alpha = 1.725$, $\beta = 1.728$, $\gamma = 1.737$. In slides the double refraction was found to be: $\gamma - \alpha = 0.013$, $\gamma - \beta = 0.0085$, $\beta - \alpha = 0.0045$. $2V_\gamma$ according to measurements on a universal stage is 70.3° . On the powder, separated from the knebelitic skarn ore containing the rhodonite, the spec. gravity was determined as 3.653. The coordinates of the bisectrices resulting as the mean of five measurements are as follows:

	(I10):(II0)	α	β	γ	(0I0)
ϕ	92.6°	$43.8^\circ (\pm 2.6^\circ)$	$298.4^\circ (\pm 5.8^\circ)$	$143.3^\circ (\pm 4.1^\circ)$	138.5° ^a
ρ	90°	$78.2^\circ (\pm 2.3^\circ)$	$40.8^\circ (\pm 3.8^\circ)$	$52.3^\circ (\pm 4.7^\circ)$	90°

^a From one measurement.

In the slides thin twinning lamellae after (010) are common.

The iron rhodonite occurs as microscopic grains in a knebelite-ore, composed chiefly of knebelite and some garnet. The content of the rhodonite in the ore does not exceed 5 vol. per cent.

SOBRALITE AND IRON RHODONITE FROM V. SILVBERG

M. Weibull in 1884 described a rhodonitic mineral characterized by a high content of iron,⁴⁰ and therefore he named it iron rhodonite. In his treatise on the sobralite from Tunaberg J. M. Sobral mentions a number of optical characters, determined by him on a specimen from V. Silvberg and emphasizes the differences in the optical properties of this mineral and the sobralite from Tunaberg. A similar distinction had been made previously by J. Palmgren.⁴¹ As the true position of the mineral nevertheless remained in doubt, a study of it was undertaken by the present writer. For this purpose two slides of a specimen from the State Museum, collected by Weibull and designated by him as iron rhodonite, were examined. In the specimen considerable homogeneous aggregates of the mineral in question and of a dark green hedenbergite (called Mn-

⁴⁰ *Kungl. Vet. Akad. Övers.*, 1884, No. 9, p. 29.

⁴¹ Compare below.

hedenbergite by Weibull), alternate with each other. In the slides the former mineral is shown to possess the same optical properties as the sobralite from Tunaberg. Hence the present writer drew the conclusion that the mineral analyzed by Weibull was in reality not an iron rhodonite but sobralite. However, the statements by Sobral and Palmgren were not in accordance with this view and for this reason a survey was made also on Weibull's original material, which is deposited in Lund. Of this material I received one specimen from Prof. A. Grönwall and a sample of crushed pieces of a mineral called iron rhodonite. In the former the mineral is distributed in a similar manner as in the specimen first described, though its amount is less. When examining slides of both specimens from Lund it appeared that in both cases the mineral associated with the hedenbergite is an iron rhodonite and not a sobralite. Thus in the same mineral occurrence both sobralite and iron rhodonite are associated with the monoclinic hedenbergite, which is the dominant mineral. Both the triclinic pyroxenes are similar in appearance, and it is not possible to distinguish them by megascopic properties. Both are colored yellowish red-brown and are developed as anhedral grains. But in determining the spec. gravities it was found that the sobralite was considerably heavier than the iron rhodonite (3.717 as compared with 3.657). Also the refraction showed a considerable difference.

The properties determined by Weibull are the following: the cleavage angle is $87^{\circ}15'-87^{\circ}49'$. Sometimes also inferior cleavages occur, evidently parallel to (001) and forming an angle of about 70° with the former. Specific gravity was found to be 3.672 at 15° . In the slides the mineral is shown to be rather rich in inclusions, partly consisting of a feebly greenish mineral (Mn-hedenbergite), partly of small magnetite grains, more rarely also of calcite and silvbergite (Mn-bearing grünerite). In the slides studied by me no inclusions of hedenbergite were seen, but both the triclinic pyroxenes are rather rich in inclusions which may consist of grünerite, although the size is, for the most part, too small to permit definite determination. The triclinic character of the pyroxenic compounds was established by Weibull on sections parallel to (010) and (100). One complete and two incomplete analyses were made by him. After corrections on account of the inclusions present the values given in column 13 of Table 1 were obtained. According to the analysis the mol. proportions of MnSiO_3 and FeSiO_3 approach 1:1

(43.6:39.8). The amount of CaO at the same time is considerable (12.8 mol. per cent) and that of MgO is small (3.8).

From the description by Weibull it is not apparent if the mineral analyzed by him was an iron rhodonite or a sobralite. The extinction angles and the spec. gravity reported by him indicate rather the former than the latter, although the values recorded are intermediate in character. On account of this the sobralite obtained from the State Museum was separated from the Mn-hedenbergite. This was done with Clerici's solution. Though the solution was kept as near to the spec. gravity of the mineral as possible and the separation was repeated, small inclusions of grünerite could not be avoided, and their amount in the resulting powder was considerable, perhaps amounting to 8–10 per cent by volume. Any possible remnants of carbonate were removed by means of hydrochloric acid. The analysis was made by Dr. Bygdén and the result is quoted under No. 14 in Table 1. From the analysis it is evident that the material analyzed by Weibull was a sobralite, although the values obtained by him are somewhat different from those of Bygdén. This is due partly to the corrections made by Weibull, but also apart from them a considerable difference is found in the proportions of FeO and MnO. Probably the cause of the difference is partly to be sought in the purifying method used by me, but it is also possible that the specimen analyzed by Weibull contained some iron rhodonite. In any case the more correct composition of the sobralite is shown by Bygdén's analysis, though this also includes slight admixtures of grünerite.

On the other hand, it is probable that the material studied microscopically by Weibull, came from a specimen of iron rhodonite as the spec. gravity determined by him approximately agrees with this mineral.

In slides of the analyzed specimen the sobralite appears as anhedral grains of varying dimensions (up to 3 mm.). The different individuals are often intimately interwoven with each other and in some cases penetration twinning is seen. In these cases the grains are composed of several smaller parts belonging to two individuals. In the slides the boundaries of the parts show a tendency to assume the form of straight lines oriented parallel to the face (001), the one individual at the same time being turned 180° about an axis perpendicular to (010). Evidently the twinning phenomenon is the same as in the Gåsborn rhodonite, though the bounding faces in the

sobralite are more irregularly developed. Locally also the general twinning lamellae parallel to (010) occur.

The optical properties of the sobralite were found as follows: $\alpha = 1.738$,⁴² $\gamma - \alpha = 0.017$, $\beta - \alpha = 0.014$. From this we get $\beta = 1.752$, $\gamma = 1.755$, and from the indices $2V_\gamma = 42^\circ 48'$. The direct measurement gave as a result $2V_\gamma = 41.6^\circ$. On the powder the spec. gravity was found to be 3.717.

The coordinates of the bisectrices, resulting from an average from three measurements, are:

	(I10):(II0)	α	β	γ
ϕ	$92^\circ 32'$ ^a	$18.7^\circ (\pm 1^\circ)$	$266^\circ (\pm 1.5^\circ)$	$136.6^\circ (\pm 2.6^\circ)$
ρ	90°	$60.9^\circ (\pm 0.9^\circ)$	$53.7^\circ (\pm 2.0^\circ)$	$48.5^\circ (\pm 1.4^\circ)$

^a The value given by Weibull. The mean of the measurements on the universal stage is 92.2° .

On comparing the positions of the corresponding points on the stereographic projection of Fig. 8 with those of the rhodonites, and the iron rhodonites, the optical discontinuity between sobralite and the minerals named is clearly demonstrated. The same is shown by the size of the axial angle, which in the rhodonitic varieties varies but slightly and which for the members of similar CaO content is about 70° , whereas sobralite has an angle of about 42° .

For the iron rhodonite, associated with the Mn-hedenbergite from V. Silvberg, the following coordinates were obtained from three measurements:

	(I10):(II0)	α	β	γ
ϕ	93.3°	$44.4^\circ (\pm 2.7^\circ)$	$294.3^\circ (\pm 5.6^\circ)$	$143.3^\circ (\pm 2.4^\circ)$
ρ	90°	$76.0^\circ (\pm 0.7^\circ)$	$36.0^\circ (\pm 2^\circ)$	$57.2^\circ (\pm 2.3^\circ)$

The measured axial angle $2V_\gamma$ is 76.9° and the spec. gravity was found to be 3.657.

SOBRALITE AND IRON RHODONITE FROM TUNABERG

The sobralite from this locality was found by J. Palmgren.⁴³ Ac-

⁴² Determined by the immersion method.

⁴³ *Bull. Geol. Inst. of Upsala*, Vol. XIV, p. 173, 1917.

cording to him the mineral forms "eine Aussonderung in Form einer einige dm. breiten Ader. Diese Aussonderung bestand aus einem Pyroxenmineral, welches im Handstück bräunlich mit einem Stich ins Lila ist sowie aus Manganfayalit und Spessartin." In the pure powder the grains of the triclinic pyroxene are slightly lilac-colored. Palmgren quoted an analysis made by R. Mauzelius, reported here as No. 15 in Table 1. The spec. gravity determined by Dr. Mauzelius was 3.60. Palmgren's report was accompanied by a preliminary determination of the optical orientation, made by J. M. Sobral. Later Sobral published a more exhaustive description of the mineral.⁴⁴

Palmgren seems to have regarded the pyroxene contained in the specimen analyzed as homogeneous. In Sobral's description is mentioned the fact that the sobralite in the slides studied by him was associated with diopside, an asymmetrical pyroxene, olivine and spessartite. The other asymmetrical pyroxene present is compared by Sobral with the iron rhodonite from V. Silfberg. Sobral is of the opinion that this mineral forms a separate species and that it is not a rhodonite nor a sobralite though it optically stands nearer to sobralite than to rhodonite on account of its optically positive character. Evidently this assumption is due to the erroneous statement in the handbooks of the optical character of rhodonite, which is taken from the old investigations of G. Flink.

* The writer studied the same specimen as that from which Sobral prepared his slides (RM. 172284). In agreement with him the writer found two asymmetrical pyroxenes, the one being sobralite, the other rhodonite with the optical properties of an iron rhodonite. Of the two pyroxenes the latter is present in greater quantity than the former. Mn-fayalite and garnet are present in rather large quantities and in addition the writer found small amounts of grünerite, some apatite and traces of a carbonate. The diopside recognized by Sobral occurs in subordinate amount. It is distinguished from the other pyroxenes by its high double refraction (about 0.030). The appearance of the pyroxenes and their mutual relations have already been described (see Fig. 2).

As it is not evident from Palmgren's paper whether the specimen on which the analysis was made is the same as that which was used for Sobral's slides, a new analysis was made on the specimen microscopically examined by Sobral and me. For this purpose the pyrox-

⁴⁴ *Bull. Geol. Inst. of Upsala*, Vol. XVIII, p. 47, 1921.

enes were separated from the other minerals by Clerici's solution. The resulting powder had a spec. gravity of about 3.62. The analysis was made by Dr. Bygdén and is quoted as No. 16 in Table 1. It is in good agreement with Mauzelius' analysis and also the value of the spec. gravity is similar. Both the analyses thus correspond to a mixture of iron rhodonite and sobralite with a small admixture of diopside.

Sobral determined the following properties of the sobralitic pyroxene: $\gamma - \alpha = 0.0200$, $\gamma - \beta = 0.0175$, $\beta - \alpha = 0.0025$, $2V_\gamma = 41.1^\circ$, $\rho > \nu$. From the first and the last values of the double refraction we get an axial angle of 41.4° . The cleavage angle was found to be 91.5° .

From the measurements quoted by Sobral the present writer has graphically deduced the following coordinates of the bisectrices:

	(I10):(II0)	α	β	γ
ϕ	91.5°	15.7°	265.4°	135.4°
ρ	90°	62.4°	56.8°	47°

I have recorded the following values: $\gamma - \beta = 0.0155$, $\beta - \alpha = 0.0025$. From this $\gamma - \alpha$ is 0.0180 , and $2V_\gamma = 43.8^\circ$. $2V_\gamma$ was measured as $41.2^\circ (\pm 0.6^\circ)$.

The coordinates of the cleavages and the bisectrices resulting from five measurements are as follows:

	(I10):(II0)	α	β	γ
ϕ	92°	$14.2^\circ (\pm 5.4^\circ)$	$264.7^\circ (\pm 4^\circ)$	$136.9^\circ (\pm 5.1^\circ)$
ρ	90°	$62.2^\circ (\pm 4^\circ)$	$56.5^\circ (\pm 6.7^\circ)$	$46.2^\circ (\pm 5.8^\circ)$

The values of the separate measurements vary a good deal on account of the somewhat deformed state of the mineral.

The values obtained by me are in good agreement with those of Sobral. Only the double refraction is somewhat lower in my measurements. No attempt to determine the refraction was made on account of the nonhomogeneous character of the powder.

On the iron rhodonite the following coordinates resulted from three measurements:

	(110):(110)	α	β	γ
ϕ	92.15°	40.6° ($\pm 0.9^\circ$)	296.2° ($\pm 1.4^\circ$)	141.0° ($\pm 2.5^\circ$)
ρ	90°	76.8° ($\pm 1.7^\circ$)	43.2° ($\pm 1.8^\circ$)	53.0° ($\pm 4.3^\circ$)

The axial angle $2V_\gamma$ was found to be 68.3° . Thin twinning lamellae parallel to (010) are seen locally.

PYROXMANGITE

This mineral has been described by W. E. Ford and W. M. Bradley from specimens coming from Iva, Anderson county, South Carolina. The mean of two analyses by Bradley is quoted as No. 17 in Table 1. According to the analysis the mineral represents a nearly pure Fe-Mn-silicate with subordinate admixtures of CaO and Al_2O_3 . The amount of FeO is somewhat greater than that of MnO. The axial angle was determined as positive and approximately 30° . From the measurements quoted it appears that the mineral is triclinic and has a cleavage angle of $91^\circ 50'$. In addition to the usual two main cleavages partings occur parallel to (010). Whether the optical orientation is in accordance with that of sobralite is not clear from the measurements given.

* * * * *

THE OPTICAL ORIENTATION OF THE TRICLINIC PYROXENES

On the stereographic projection of Fig. 8 the positions of the bisectrices are plotted according to the coordinates given in the above. The positions of the bisectrices in relation to the cleavage faces are obtained at once when making the measurements on sections in which the two chief cleavages are accessible. The position of the face (001) and of the obtuse crystallographic angle β , on the other hand, can not be located in this way. This can only be accomplished in a section whose position is determined in relation to faces of known crystallographic indices. In order to accomplish this two crystals of rhodonite from Harstigen (RM. 13360) were selected and measured on a goniometer. The following faces and angles were recorded:

Crystal 1		Crystal 2	
(221):(110)	31°15'	(221):(110)	31°19'
(110):(001)	86°28'	(221):(110)	76°54'
(110):(110)	92°23'	(110):(110)	92°20'
(110):(001)	68°36'	(100):(110)	44° 9'
(221):(001)	62°18'		

Crystal 1 was cemented with the face $(2\bar{2}1)$ on an object glass and cut down in this position. In the resulting slide the bisectrix β was observable. On crystal 2 an artificial face was cut at an angle of 4 degrees to $(\bar{1}00)$ and used for the preparation of the slide in a similar way as in the foregoing case. In this slide α was accessible. In both cases the orientation obtained was identical. The results of both measurements are brought together in Fig. 7. The orientation shown here is in agreement with that previously arrived at by Hey, but it does not agree with that of H. Buttgenbach and M. Melon,⁴⁵ whose results differ from that presented here by a rotation of the bisectrices of approx. 90° about the vertical c -axis.

The orientation shown in Fig. 7 is valid for the rhodonites. Concerning the crystallographic development of sobralite we do not

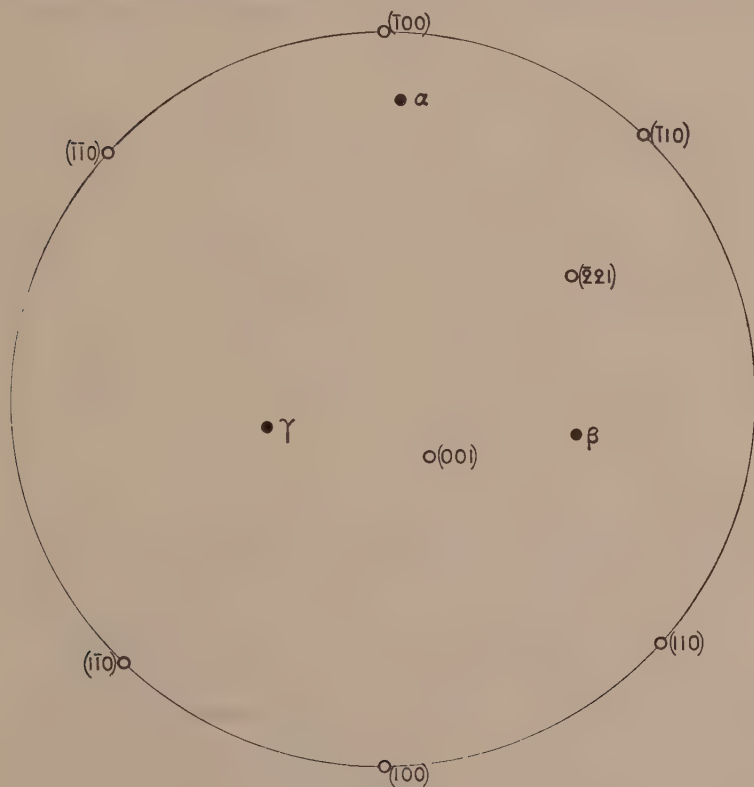


FIG. 7.

⁴⁵ *Op. cit.*

twinning lamellae is not the same as in the monoclinic pyroxenes, the twinning face here being (100). In the iron rhodonite from Gåsborn and in the sobralite from V. Silfberg a modification of the twinning mentioned above is seen, the actual rotation of the individuals being the same, but the planes of contact are (001). Also more irregular intergrowths of the twinned individuals occur.

In the bustamites simple twinning parallel to the cleavage faces (110) or $(\bar{1}10)$ are often developed.

SUMMARY OF THE OPTICAL PROPERTIES

The distribution of the points in the diagram of Fig. 8 offers several points of interest. If the different species of the triclinic pyroxenes were members of a related isomorphous series, this would appear in the arrangement of the points, the positions being changed continuously and in a regular manner according to the chemical variations. But this is not the case. From the diagram it is apparent that the rhodonites proper, as a result of the increase of CaO, change their positions in the diagram, though the movements occurring are not great, all points belonging to the same bisectrix being situated on a nearly straight line. The iron rhodonites lie approximately in the continuations of these lines or are only slightly displaced. The displacements may be due chiefly to the influence of the iron silicate; to some extent they can be caused by errors in the measurements. The bustamites, on the other hand, do not at all agree with the rhodonites, and the same is still more evident for the sobralites, whose orientation is very different from that of all the other triclinic pyroxenes.

The change shown in the diagram for the bustamites corresponds to an increase of the CaSiO_3 -content from 33 to 49 mol. per cent. This change is considerable and is most conspicuous at β . Evidently, if we consider a continuous further enlargement of the Ca-content as possible, the change of the optical orientation would continue in the same direction as before. In a very Ca-rich composition we should get a position of β nearly or exactly coincident with the axis of the vertical zone (the c -axis in the present projection), the other bisectrices at the same time being displaced at the periphery of the projection. Thus we should get the picture of a monoclinic or nearly monoclinic mineral, projected on the crystallographic b -axis and the orientation obtained would be about identical with the relations in wollastonite. This is shown in Fig. 9 which contains an

know more than the approximate angle of the cleavages. On the other hand, the orientation of the bustamites selected here is accidental and is only accepted for the sake of a better comparison. On account of the results obtained in this work it should more correctly be replaced by the orientation named elsewhere in this paper.

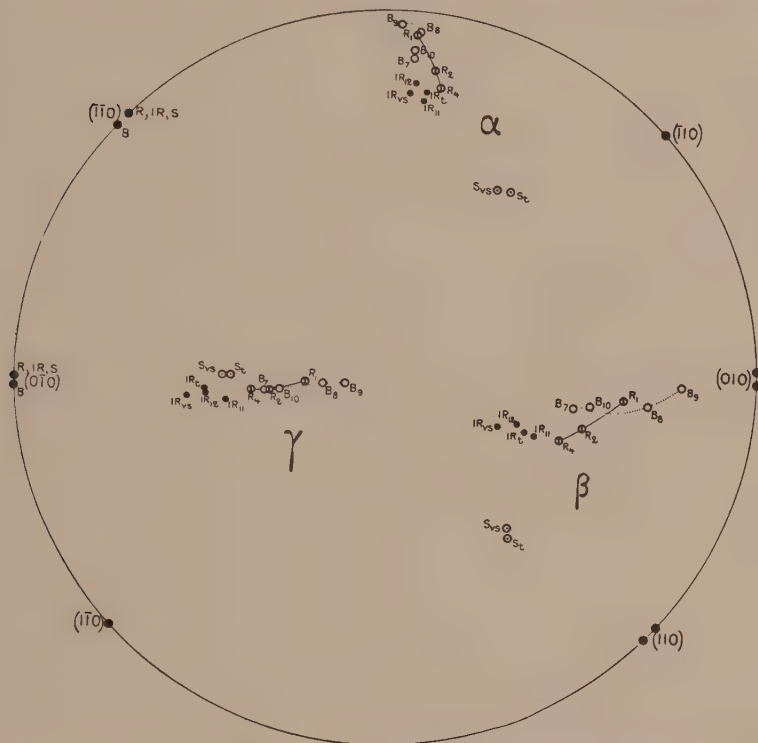


FIG. 8. Stereographic projection of the optical orientations of rhodonites (R), iron rhodonites (IR), sobralites (S) and bustamites (B). The figures of the letters refer to the figures in Table 2; *vs* = V. Silvberg, *t* = Tunaberg.

TWINNING PHENOMENA IN THE TRICLINIC PYROXENES

Twinning phenomena occur in most of the specimens examined. Most common is the appearance of thin twinning lamellae parallel to (010). Lamellae of this kind are seen both in the rhodonites and in the iron rhodonites, as well as in sobralite, but not in the bustamites. It deserves to be mentioned that according to the crystallographic orientation chosen for the rhodonite the position of the

extrapolation from the bustamites in accordance with the change outlined above. Thus, in the figure the bisectrices of the most CaO-rich bustamites have been shifted so that there is coincidence of β with the axis of the cleavage zone. The resulting orientation, thereafter, is shown in a projection similar to that of wollastonite, pro-



FIG. 9

jected with the crystallographic c -axis at the center. For this reason (110) in the ordinary orientation of the bustamite is made (100) , and $(\bar{1}10)$ as (001) . As shown in the figure the differences occurring between wollastonite and the extrapolation from the bustamites are quite small and not greater than possible errors in the measurements on the universal stage, or to possible movements of the ellipsoid around β during the supposed change of its position. This is

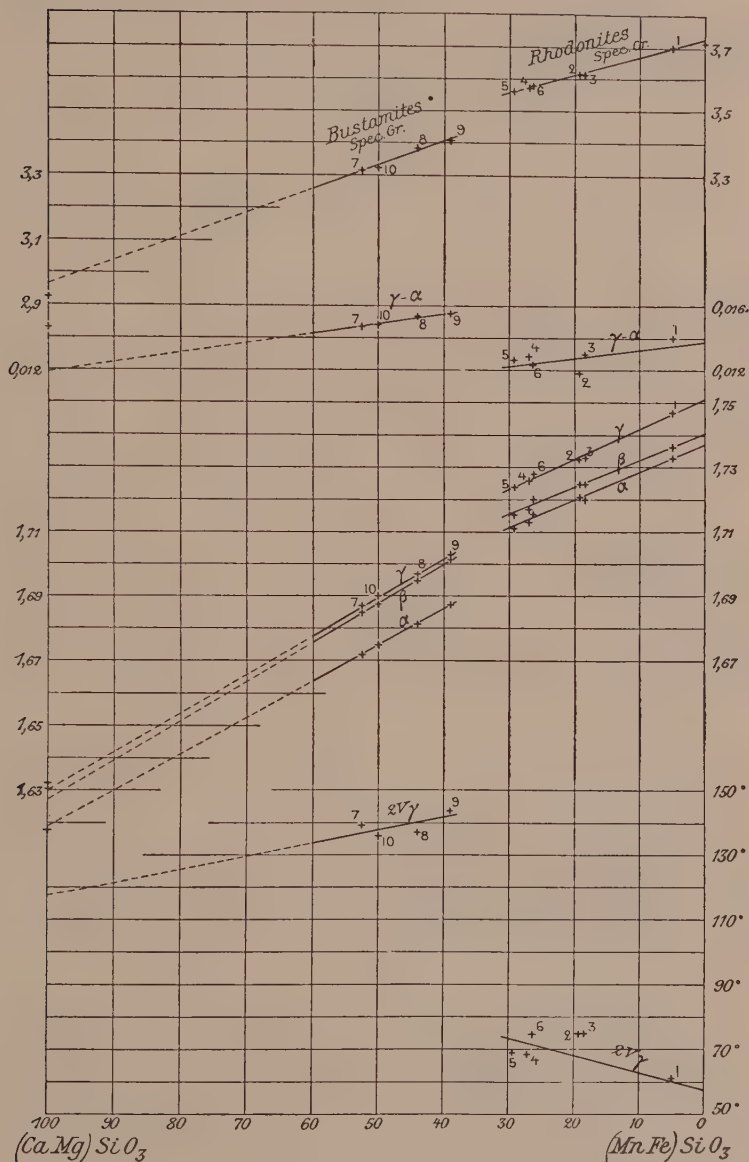


FIG. 10. The values reproduced in the diagram refer to the values in Table 2. The points on the $Ca(Mg)SiO_3$ -side are the values of wollastonite from Pargas, determined by the writer.

one of the reasons why the bustamites in this work are considered as isomorphous with wollastonite.

In Table 2 the values of the refraction, the double refraction, the spec. gravity and of the axial angles obtained from the specimens examined are assembled.⁴⁶ For the rhodonite from Harstigen the values of Hey are added. The figures of the sobralite from Tunaberg represent the mean of the values of Sobral and those of the present writer. For the rest no older determinations have been quoted, partly because they are incomplete and partly because they may not be reliable.

In reproducing the values of the iron-poor rhodonites and those of the bustamites in a two-axial diagram we shall get the picture shown in Fig. 10. The reproduction is possible only if we unite MgSiO_3 with CaSiO_3 , and FeSiO_3 with MnSiO_3 . The amounts of FeO are generally small. The amounts of MgO, however, are in most cases larger and must have some influence on the positions of the points. The influence of this oxide is to reduce the refraction and the spec. gravity. On the axial angle some reduction of the angle around γ seems to be the result of a greater admixture of MgSiO_3 . For these reasons the lines of the diagram only approximately refer to the relations in the pure Mn-Ca-series. On the other hand, the Fe-content of the specimens will, to some extent, counteract the influence caused by the Mg-component.

Of the lines shown in the diagram those of the refraction, the double refraction and of the spec. gravity are calculated as straight lines from the coordinates of the points. Only the determinations of the present writer have been used. The curves of the axial angles were deduced from the lines of the refraction. On account of the small variations in the axial angles the shape of the curves approaches that of straight lines. For pure rhodonite we obtain the following values:

$$\alpha = 1.7376, \beta = 1.7408, \gamma = 1.7514; 2V_{\gamma} = 57.5^{\circ}; \text{spec. gravity} = 3.727.$$

On the diagram the value of the spec. gravity of the artificial rhodonite found by Jaeger and Van Klooster (3.716) has been marked.

From the relations in the diagram the non-isomorphous character of the two mineral series is apparent.

⁴⁶ In the chemical formula the small amounts of Fe_2O_3 are included in FeO. BaO is joined with CaO. ZnO is not taken into consideration.

If we extend the lines originating from the coordinates of the bustamites they would have the course shown in the diagram. The end points on the CaSiO_3 -side should be those quoted below. For comparison the values of wollastonite are recorded:⁴⁷

	α	β	γ	$2V_\alpha$	Sp. Gr.
Extrapolated from the bustamites	1.6187	1.6270	1.6301	$62^\circ 32'$	2.961
Wollastonite	1.6177	1.6305	1.6323	39°	2.925

Owing to the short distance between the outermost points of the bustamites and the long extrapolation, the differences are small. Thus only a variation of 0.001 at most in the indices β and γ of one or two of the bustamites studied would be sufficient to render the extrapolated indices equal to those of wollastonite, and at the same time the axial angle would change correspondingly. At α the agreement is already sufficient. Owing to the method of measurement the size of the variation is too great to be due to errors of determinations on bustamites Nos. 7, 8 and 10, but in the case of No. 9 an error of the magnitude named is not excluded. On the other hand, variations of the size named may also be caused by admixtures of (Fe, Mg-) silicates. Even in the present state of our information the agreement on the CaSiO_3 -side of the diagram is sufficient to make the isomorphic relations of the respective minerals probable.

The relations of the iron-rich compounds are more complicated owing to considerably greater admixtures of (Ca,Mg) SiO_3 . The specimens known are also few in number. A two-axial diagram along the side MnSiO_3 - FeSiO_3 of the triangular diagram is therefore impossible. In Fig. 11 a picture of the approximate relations in the area occupied by the stability field of the rhodonites-iron rhodonites is given, showing the variation of the refraction and the spec. gravity caused by the different silicates. As is seen here, the iron compound causes a marked influence on the properties named when compared with MnSiO_3 . From the determinations of these properties an approximate statement of the proportions of these two silicates will be possible with the aid of the diagram.

⁴⁷ The figures quoted have been determined by the present writer on a wollastonite specimen from Pargas (RM. 061282).

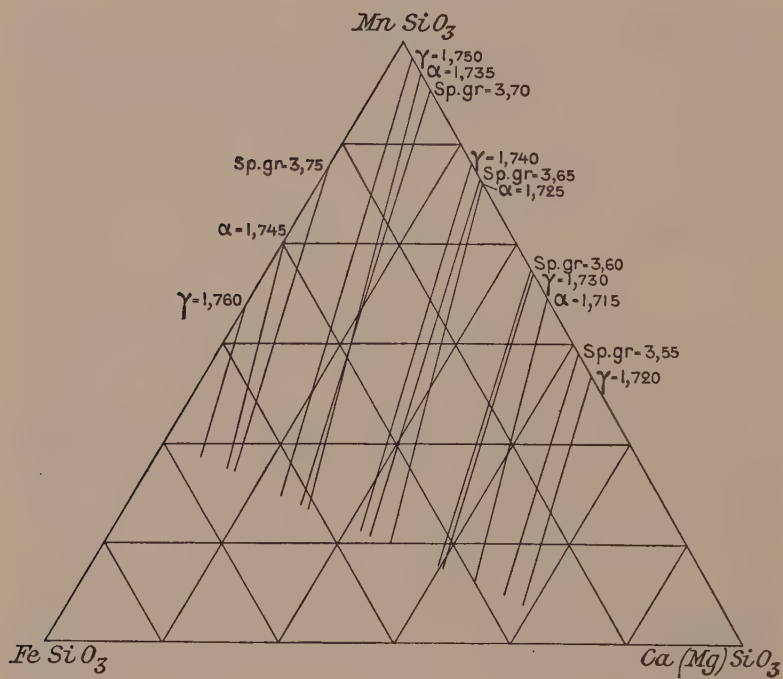


FIG. 11

TABLE I.¹

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
SiO ₂	46.13	45.86	47.46	47.51	47.42	48.16	47.78	47.66	48.31	48.27	46.56	47.78	45.12	46.53	47.92	46.91	47.14	48.29	49.84
Al ₂ O ₃	—	—	—	—	tr	—	—	—	tr	—	—	0.08	1.38	0.21	0.16	0.22	2.38	—	0.78
FeO ₂	0.15 ²	0.36	0.07 ²	0.08 ²	0.46	—	—	—	—	—	3.13	0.11	22.44	0.85	0.46	0.15	—	24.01	19.85
MnO	51.55	45.92	41.01	41.37	39.42	40.16	27.69	31.65	33.04	28.30	34.12	29.20	24.25	24.69	13.78	14.29	28.34	24.01	19.85
MgO	0.61	1.65	3.23	3.16	1.97	4.55	1.06	1.18	1.90	0.50	1.55	1.93	22.45	20.50	27.96	28.58	20.63	6.47	3.66
CaO	1.31	6.40	7.89	7.61	8.98	6.71	22.62	18.16	14.93	22.04	7.70	6.55	1.20	1.39	3.58	3.46	—	2.83	6.90
BaO	0.07	n.d.	0.08	n.d.	0.06	0.16	n.d.	0.19	n.d.	n.d.	n.d.	n.d.	5.62	5.46	6.20	5.99	1.88	17.69	18.42
ZnO	n.d.	n.d.	n.d.	n.d.	n.d.	0.31	0.21	n.d.	n.d.	0.07	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
H ₂ O	0.23	n.d.	0.26	n.d.	0.20	0.31	0.21	n.d.	n.d.	0.12	0.42	0.09	n.d.	0.39	0.28	0.37	0.33	n.d.	0.35
	100.05	100.19	100.00	99.73	100.28	100.09	99.36	99.59 ²	100.05	99.55	99.71	100.25	100.01	100.10	100.34	99.97 ⁴	100.70	99.51 ⁶	100.30
SiO ₂	7688	7643	7910	7918	7903	8027	7963	7943	8052	8045	7760	7963	7520	7755	7987	7818	7857	8048	8307
Al ₂ O ₃	—	—	—	—	—	—	—	—	—	—	—	8	135	51	16	22	233	—	76
FeO ₂	—	—	—	—	29	—	—	—	—	—	196	7	135	23	29	9	—	—	31
MnO	21	50	10	11	246	6	—	67	260	49	865	2015	3117	3429	1914	1985	3936	3335	2757
MgO	7260	6468	5776	5827	5552	5656	3900	4458	4654	3986	4806	4113	3415	2890	3938	4025	2906	909	516
CaO	152	412	807	790	492	1137	265	295	475	125	387	482	300	347	895	865	—	707	1725
BaO	234	1143	1409	1359	1604	1198	4039	3243	2666	3936	1375	1170	1004	975	1107	1070	336	3159	3289
ZnO	—	—	5	—	4	11	—	13	—	—	—	—	—	5	—	—	—	—	—
H ₂ O	128	—	144	144	111	172	117	—	—	8	—	—	—	217	156	206	183	—	194

1. Rhodonite, Vittinge (RM. 6296), analyst A. Bygdén.

2. Rhodonite, Harsigen, analyst G. Pavkull.

3. Rhodonite, Långban, Nr 1a (RM. 13448), analyst A. Bygdén.

4. Rhodonite, Långban, Nr 2 (RM. 13448), analyst A. Bygdén.

5. Rhodonite, Långban, Nr 3 (RM. 13448), analyst A. Bygdén.

6. Rhodonite, Långban, Nr 3 (RM. 13448), analyst A. Bygdén.

7. Bustamite, Långban, No. 1 (RM. 27318), analyst R. Blix.

8. Bustamite, Långban, No. 2 (RM. 13397), analyst G. Lindström.

9. Bustamite, Långban, No. 3 (RM. 43473), analyst A. Bygdén.

10. Bustamite, Franklin Furnace, (RM. 24301), analyst G. Assarsson.

11. Iron rhodonite, Gåsborn (RM. 17173), analyst G. Assarsson.

12. Iron rhodonite, Tuna Håstberg, analyst A. Bygdén.

13. Sobralite, V. Silvberg, analyst M. Weibull.

14. Sobralite, V. Silvberg, analyst A. Bygdén.

15. Sobralite and iron rhodonite, Tunaberg (RM. 172284), analyst R. Mauzelius.

16. Sobralite and iron rhodonite, Tunaberg (RM. 172284), analyst A. Bygdén.

17. Pyroxmangite, South Carolina, analyst W. M. Bradley.

18. Mn-Heidenbergite, V. Silvberg, analyst M. Weibull.

19. "Diopside" (Heidenbergite), Gillinge, analyst R. Mauzelius.

¹ All new analyses are calculated on basis of dried at 105°.² Det. as FeO₂.³ Incl. 0.27 alkalis.⁴ Hereto 0.007 TiO₂.⁵ Incl. 0.22 alk.

TABLE II.

	Mol. per cent					γ	$\gamma-\alpha$	$2V_{\gamma}$	(110):(110)		
	MnSiO ₃	FeSiO ₃	MgSiO ₃	CaSiO ₃	Sp. gr.						
1. Rhodonite, Vittinge (anal. 1)	94.69	0.27	1.98	3.05	3.70	1.733	1.737	1.747	0.014	61°	92°44'
2. Rhodonite, Harstigen (anal. 2)	80.12	0.62	5.10	14.16	3.616	1.7208	1.7251	1.7326	0.0118	75°	92°25'
3. Rhodonite, Harstigen, Hey	80.14	1.34	0.13	18.40	3.615	1.720	1.725	1.733	0.013	75°	
4. Rhodonite, Långban (anal. 4)	72.96	0.14	9.89	17.01	3.573	1.7131	1.7171	1.7260	0.0129	68.4°	92°13'
5. Rhodonite, Långban 2 (anal. 6)	70.63	0.07	14.20	15.10	3.563	1.7112	1.7153	1.7239	0.0127	69°	92°27'
6. Rhodonite, Långban 3 (anal. 5)	69.78	3.82	6.18	20.21	3.581	1.7157	1.7203	1.7281	0.0124	74.8°	92°24'
7. Bustamite, Långban 1 (anal. 7)	47.54	—	3.23	49.23	3.317	1.67198	1.68493	1.68670	0.01472	139.1°	94°35'
8. Bustamite, Långban 2 (anal. 8)	55.29	0.83	3.66	40.22	3.386	1.68153	1.69487	1.69691	0.01538	136.9°	95°22'
9. Bustamite, Långban 3 (anal. 9)	57.78	3.23	5.90	33.10	3.410	1.6874	1.7014	1.7029	0.0155	143.8°	94°57'
10. Bustamite, Franklin Furnace (anal. 10)	49.23	0.61	1.54	48.62	3.324	1.67493	1.68766	1.68973	0.01480	135.9°	95°11'
11. Iron rhodonite, Gåsborn (anal. 11)	66.38	9.27	5.36	18.99		1.7205	1.7251	1.7326	0.0121	76.4°	92°24'
12. Iron rhodonite, Tuna Hästberg (anal. 12)	52.77	26.03	6.19	15.01	3.653	1.725	1.728	1.737	0.013	70.3°	92°36'
13. Sobralite, V. Silvberg (anal. 14)	37.66	45.04	4.52	12.77	3.717	1.738	1.752	1.755	0.0165	41.6°	92°32'
14. Sobralite, Tunaberg			—	4.68	3.80				0.019	41.2°	91°46'
15. Pyroxmangite, Iva, S. Carolina (anal. 17)	40.48	54.84								30°	91°50'
16. Mn-Hedenbergite, V. Silvberg (anal. 18)	11.21	41.12	8.72	38.95	3.55						
17. Diopside (Hedenb.) Gillinge (anal. 19)	6.18	33.76	20.66	39.39	3.544				0.032	56.5°	

THE CRYSTAL STRUCTURE OF IODOFORM

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In this paper we wish to report the results of an x -ray investigation, made in 1926, of the crystal structure of iodoform. As our results are in complete accord with those obtained by Nitta,¹ whose work became known to us as ours was nearing completion, the presentation will be brief.

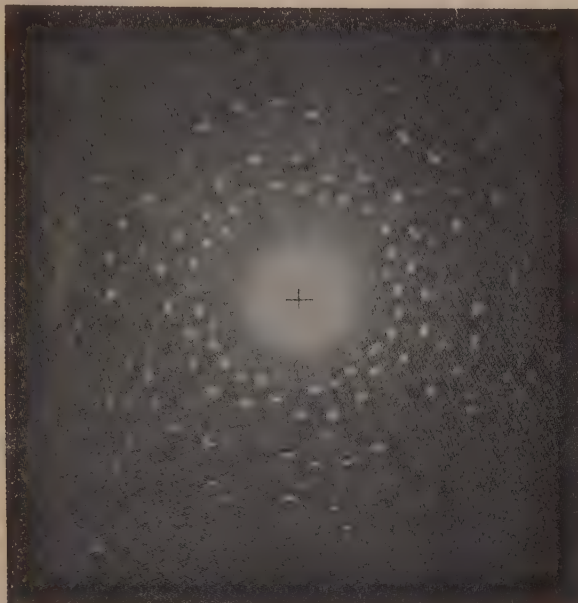


FIG. 1. Laue photograph taken with x -ray beam parallel to the c -axis.

Iodoform crystallizes in the hexagonal system.² The crystals used, obtained by recrystallization from acetone, showed faces of the forms $\{0001\}$ and $\{10\bar{1}1\}$. Laue photographs were obtained (1) with the x -ray beam (from a tungsten target) parallel to the c -axis (Fig. 1), and (2) with the beam making an angle of about 5° with that axis. Reflection spectra were obtained (3) from a (0001) face and (4) from a $(10\bar{1}1)$ face, a calcite spectrum being in each

¹ Nitta, *Sci. Papers Inst. Phys. Chem. Res. (Tokyo)*, **4**, 47, 1926.

² Groth, *Chemische Krystallographie*, **3**, 4.

case produced at the same time for comparison purposes. A reflection spectrum from (0001) was also obtained (5) without the calcite spectrum, an a -axis being in the axis of rotation (Fig. 2). For all of these spectra a molybdenum target x -ray tube was used and the crystal was oscillated at constant angular velocity through an angle of 20° .

The smallest unit cell (with either of the two possible orientations of the a -axes) which will permit the assignment of integral

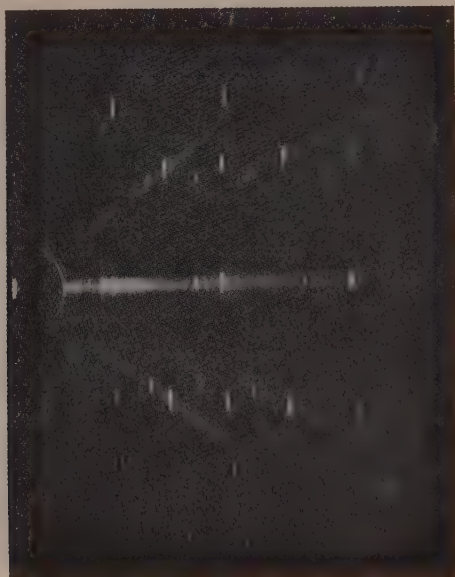


FIG. 2. Photograph obtained by oscillating a crystal about an a -axis. The lines in the principal spectrum are the (0002), (0004), (0006), and (0008) ($K\beta$ only) reflections.

indices to all the reflections in the oscillating crystal photographs has the approximate dimensions $a_0 = 6.8 \text{ \AA}$ and $c_0 = 7.5 \text{ \AA}$. Larger units would leave unexplained large classes of absences. The Laue data also lead to a unit cell of these dimensions. Smaller units would require for some of the reflections wave-lengths known to be absent from the incident x -ray beam. The comparison spectra with calcite gave $d_{0002} = 3.76_2 \text{ \AA}$ and $d_{1011} = 4.64_5 \text{ \AA}$. From these can be calculated the values $a_0 = 6.81_8 \text{ \AA}$ and $c_0 = 7.52_4 \text{ \AA}$, giving an axial ratio (c/a) of 1.10_4 , in good agreement with the crystallographically

determined value,³ of 1.1084. The density, calculated for two molecules per unit, is 4.29 g./cc. to be compared with the observed value⁴ of 4.1 g./cc.

In view of the negligibly small reflecting power of carbon and hydrogen relative to that of iodine, one cannot be sure that the true unit of structure is not larger than this, but our data show that the arrangement of iodine atoms at least, can be described in terms of this size of unit. In our determination of the space group and of the parameters it has also been necessary to ignore the scattering produced by the lighter atoms.

The symmetry of the "symmetrical" Laue photograph (Fig. 1) is such as would only be produced by a structure isomorphous with one of the point groups $C_3^h(A_3 \cdot P)$, $C_6(A_6)$ or $C_6^h(A_6 \cdot P \cdot C)$. The basic lattice is the hexagonal, rather than the rhombohedral, since many reflections were observed for which $(2h+k+l)/3$ is not integral. Although the 2nd, 4th, 6th and 8th order reflections from (0001) were observed, with strong or medium intensities, no odd order reflections from this face were found. Other l odd reflections were present.

These observations eliminate⁵ all arrangements of iodine atoms except one, which may be derived from either of the space groups C_6^6 or C_6^h . The coordinates of the iodine atoms in this distribution are $xy0$; $y-x, \bar{x}, 0$; $\bar{y}, x-y, 0$; $\bar{x}\bar{y}\frac{1}{2}$; $x-y, x, \frac{1}{2}$; $y, y-x, \frac{1}{2}$.

Possible values of the parameters x and y were limited greatly by means of comparisons from the Laue photograph reproduced in Fig. 1, the procedure being similar to that outlined by Wyckoff.⁶ All parameter values were considered which would make the distance of each iodine from the nearest trigonal axis between 1.8 and 2.1 Å. The comparisons listed in Table 1 eliminated all but three small regions, namely

$$(1) \ x = .117 - .135; \ y = .304 - .338$$

$$(2) \ x = .298 - .338; \ y = .185 - .202$$

$$(3) \ x = .340 - .365; \ y = .032 - .058$$

³ Pope, *J. Chem. Soc.*, **75**, 46, 1899.

⁴ *Int. Crit. Tables*, **1**, 176.

⁵ Wyckoff, *Analytical Expression of the Results of the Theory of Space Groups*, *Carnegie Inst. Publ.*, **318**, Washington, 1930; *Z. Krist.*, **63**, 507, 1926. Astbury and Yardley, *Phil. Trans. Roy. Soc. (London)*, **A224**, 221, 1924. Mark, *Die Verwendung der Röntgenstrahlen in Chemie und Technik*, Barth (Leipzig), 1926, pp. 392-393.

⁶ Wyckoff, *The Structure of Crystals*. Chem. Cat. Co. (New York, 1924) p. 217.

TABLE 1. USEFUL DATA FROM LAUE PHOTOGRAPH (1)

$\{hkl\}$	d_{hkl}	λ	Intensity
2351	1.33	.45	0.6
		.44	0.6
		.42	0.6
3251	1.33	.45	2.0
		.44	2.0
		.42	2.0
4151	1.27	.46	2.0
		.44	2.0
		.41	1.0
1451	1.27	.46	2.0
		.43	2.0
		.42	1.5
2572	.92	.48	.05
		.47	.05
		.44	.05
1672	.88	.43	.3
		.41	.2
		.40	.2
6172	.88	.43	.4
		.41	.4
		.40	.3
6283	.78	.45	.2
3471	.96	.27	0
		.26	0
4371	.96	.28	.15
		.26	.05

Comparisons from above:

3251 > 2351	6172 > 2572
4151 > 2351	6283 > 2572
1451 > 2351	6172 > 1672
1672 > 2572	4371 > 3471

At this point in the analysis we became aware of Nitta's work. He had determined the unit distances as $a_0 = 6.87 \text{ \AA}$ and $c_0 = 7.61 \text{ \AA}$,

had arrived at the same arrangement of iodine atoms and had calculated the parameter limits to be

$$x = .346 - .362; y = .038 - .056$$

with the most probable values as

$$x = .352; y = .047.$$

These parameter values are in good agreement with our set (3) above. On making calculations to ascertain whether or not any of his data are in disagreement with our parameter ranges (1) and (2) we found that this is true of his comparison $13\bar{4}1 > 31\bar{4}1$. The reflections from planes of these forms on our Laue photograph (1) are mixtures of first and second orders. Examination of photograph (2) however showed reflections from such planes having relative intensities agreeing with those obtained by Nitta (See Table 2).

TABLE 2. USEFUL DATA FROM LAUE PHOTOGRAPH (2)

$\{hkl\}$	d_{hkl}	λ	Intensity
$31\bar{4}1$	1.60	.46	1.0
		.43	1.0
$13\bar{4}1$	1.60	.41	3.0

Comparison from above: $13\bar{4}1 > 31\bar{4}1$

The distribution of iodine atoms arrived at is represented in Fig. 3. If it be assumed that the carbon and hydrogen atoms require

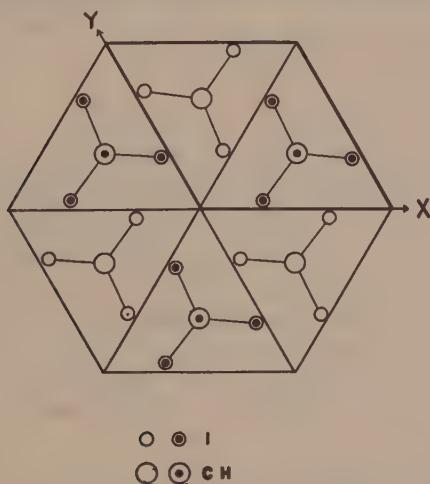


FIG. 3. A projection of a portion of the structure on a (0001) plane, showing the distribution of atomic centers and of C-I bonds.

neither a larger unit of structure nor a lower symmetry class than deduced from the experimental data and that the CHI_3 molecule maintains its identity in the crystal, it follows that the space group must be C_6^8 (rather than C_{6h}^2) and that the carbon and hydrogen atoms must be on three-fold symmetry axes. Of the two possible arrangements

$$(a) 00u; 0, 0, \frac{1}{2}+u \quad (b) \frac{1}{3}\frac{2}{3}u; \frac{2}{3}, \frac{1}{3}, \frac{1}{2}+u$$

the second, (b), is by far the more likely: the distance between iodine atoms in the same molecule is less than the distance between neighboring iodine atoms in different molecules and the molecules are in a "close-packed" array each roughly equidistant from 12 others rather than crowded together in parallel strings with each close to but two others and large distances between strings (an arrangement which should result in very ready cleavage parallel to the string axes). The parameter u_C is probably between .50 and .60, the latter being the value it would have if each carbon were at the center of a regular tetrahedron with iodines at three corners. This gives a C-I distance (from Nitta's "most probable" parameter values and our own unit distances) between 2.06 Å and 2.24 Å, agreeing well with the sum (2.12 Å) of half the I-I distance⁷ (2.70 Å) in crystalline I_2 and half the C-C distance⁸ (1.54 Å) in the diamond. The value of u_H is probably approximately $u_C + .15$, which would give a C-H distance of 1.13 Å, the value computed from band spectra assumed to be due to a CH molecule.⁹ Each H is near the center of a group of 6 I atoms, three in the same molecule and three in adjacent molecules.

Each iodine center is 3.56 Å from the other two iodines in the same molecule and 4.39 Å from four, 4.38 Å from two, 4.46 Å from two, and 3.91 Å from two others in adjacent molecules. These last four distances are, as would be expected, not far from the distances between iodine atom centers in adjacent molecules in SnI_4 ¹⁰ (4.21 Å), CdI_2 ¹¹ (4.21 Å), HgI_2 ¹² (4.10 Å) and I_2 ⁷ (3.54 and 4.34 Å).

Lawrence Brockway and Linus Pauling of the California Institute of Technology have observed the scattering of Mo $K\alpha$ by a

⁷ Harris, Mack and Blake, *J. Am. Chem. Soc.*, **50**, 1583, 1928.

⁸ W. H. Bragg and W. L. Bragg, *X-Rays and Crystal Structure*, G. Bell and Sons (London), p. 106.

⁹ *Int. Crit. Tables*, **5**, 412.

¹⁰ Dickinson, *J. Am. Chem. Soc.*, **45**, 958, 1923.

¹¹ Bozorth, *J. Am. Chem. Soc.*, **44**, 2232, 1922.

¹² Huggins and Magill, *J. Am. Chem. Soc.*, **49**, 2357, 1927.

saturated solution of iodoform in benzene. They obtained maxima, other than the benzene maxima, at $13^{\circ} 13'$ and $24^{\circ} 15'$ (total angles of diffraction), corresponding to a distance between iodine atoms in the molecule of 3.86 Å and 3.80 Å respectively, in each case ± 0.2 Å, using Debye's formula for scattering by molecules.

The arrangement of carbons, of hydrogens, or of molecules considered as a whole is that of hexagonal close-packing, except for a contraction in the direction of the hexagonal axis from $c_0/a_0 = 1.63$ to $c_0/a_0 = 1.10$. Probably more significant however is the fact that the arrangement of iodine atoms is also approximately that of hexagonal close-packing. It would be exactly that if $x = .333$, $y = 0$ and $c_0/a_0 = 1.633/\sqrt{3} = .943$.

SUMMARY

Using Laue and oscillating crystal x-ray photographs, the arrangement of iodine atoms in CHI_3 has been determined. The hexagonal unit cell has the dimensions $a_0 = 6.81_8$ Å, $c_0 = 7.52_4$ Å, and contains two molecules. The space group is C_6^6 , the iodine atoms being in the positions

$$xy0; \quad y-x, \bar{x}, 0; \quad \bar{y}, x-y, 0; \quad \bar{x}\bar{y}\frac{1}{2}; \quad x-y, x, \frac{1}{2}; \quad y, y-x, \frac{1}{2}$$

with $x = .346 - .362$ and $y = .038 - .056$. The carbon and hydrogen atoms are in all probability on three-fold symmetry axes, in positions

$$\frac{1}{3} \frac{2}{3} u; \frac{2}{3}, \frac{1}{3}, \frac{1}{2} + u$$

with u_C between .50 and .60 and with u_H approximately equal to $u_C + .15$.

The chief factors producing this type of structure seem to be the tendency of the large iodine atoms to form a close-packed assemblage and the tendency of the hydrogen ends of the molecules to be surrounded by iodine atoms.

PERSISTENCE OF FELDSPAR IN BEACH SAND

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Although the amount of detrital feldspar in a sand, and the degree of alteration of the feldspar are considered some indication of climatic and topographic conditions during deposition, comparatively few quantitative analyses showing amounts of feldspar in recent sediments seem to have been published.¹ This paper gives the results of a study of the feldspars in a series of beach sands for which the source of material and conditions of transportation and deposition are fairly well known, and attempts a discussion of some of the factors affecting the proportion of feldspar present.

The samples used were collected from the Atlantic beach between Charleston, South Carolina, and Miami, Florida, while the writer was in the employ of the Florida Geological Survey. There was no particular reason except that of convenience for limiting the investigation at Charleston on the north, but no grain counts were made on the sand from south of Cape Florida, near Miami, because the beach sand is almost entirely calcium carbonate, and detrital grains of either quartz or feldspar are scarcely to be found.

SOURCE AND TRANSPORTATION OF SAND

The rivers entering the Atlantic ocean in North Carolina, South Carolina and Georgia carry large amounts of sand, part of which is derived from the weathering of the crystalline rocks of the Piedmont Plateau, and part from the sedimentary Coastal Plain formations. Since the rocks of the Piedmont region are largely feldspathic, the sand coming directly from them as a source contains more feldspar than that from the Coastal Plain formations which have been subjected to weathering and leaching through a long period of time. In addition to the sand carried to the sea by rivers, there is some on the beaches which is derived directly from marine erosion of sand formations mostly of Pleistocene to Recent age. Southward from the mouth of Altamaha River near Brunswick,

¹ A few references on detrital feldspar in sediments are: Milner, H. B., *Sedimentary Petrography*, second edition, pp. 217, 432, 448. Mackie, W., Feldspars in Sedimentary Rocks as Indicators of Climate: *Trans. Edinburgh Geol. Soc.*, 1898, p. 443. Reed, R. D., Recent Sands of California: *Jour. Geol.*, vol. 38, pp. 223-245, 1930.

Georgia, all the way to Miami there is very little contribution of sand by the rivers draining into the Atlantic, and none at all from beyond the limits of the Coastal Plain. All the way along the shore in the region under consideration the movement of sand is to the southward. The sand is transported by wave action on the beach and by shore currents in shallow water. Except for shell fragments and grains of calcium phosphate, the beach sand on the east coast of Florida comes from the north, and has essentially the same source as the sand on the coast of Georgia.

In the northern part of the region from which the beach sands were studied, that is, in South Carolina and Georgia, the proportion of feldspar in the sand may be considered some indication of how this mineral is able to stand weathering and stream transportation in a humid, warm-temperate climate. The proportion of feldspar in the beach sand farther to the south in Florida may show something regarding the resistance to abrasion and solution during alongshore transportation in sea water.

COLLECTION OF SAMPLES

While the method of collecting at all of the localities was not absolutely uniform, in most instances the sample represents a vertical cut through a depth of $\frac{1}{2}$ foot to 2 feet at or near the ordinary high tide line. With the exception of sample No. 8094 from Tybee, Georgia, which contains 4.6 percent of minerals of specific gravity above 2.85, sands in which heavy minerals were very much concentrated were avoided in selecting material for the study of the feldspars.

LABORATORY PROCEDURE

The sands containing an appreciable amount of shell fragments were treated with dilute hydrochloric acid; this was necessary for all samples from Melbourne southward, and for some of those from north of there. The relative amounts of quartz and potash-feldspar were determined by microscopic examination of the light portion floated in bromoform of specific gravity 2.85. Grain counts were made on temporary mounts in a liquid of refractive index 1.530, and in some instances also, on permanent mounts in Canada balsam. The potash-feldspar was distinguished from quartz by its lower refractive index. All of the potash-feldspar grains in the slides examined were counted, but the quartz grains were counted in fields uniformly spaced so as to cover systematically a certain fraction of the slide, usually between $\frac{1}{4}$ and $\frac{1}{2}$, and the total number

of quartz grains was estimated from that. The number of grains examined was generally between 2000 and 7000 for each sample. In some of the sands a very little plagioclase may have been counted with the quartz.

DESCRIPTION OF FELDSPARS PRESENT

Microcline is the most abundant feldspar present throughout the whole length of the beach under consideration. In making the grain counts, no attempt was made to distinguish between orthoclase and microcline, the two being counted together as potash-feldspar (Kf). In sample No. 8079 from Folly Beach near Charleston, S. C., there is some plagioclase as basic as labradorite, and the total plagioclase is estimated to amount to about half as much as the potash-feldspar, which, after allowing for the presence of minerals

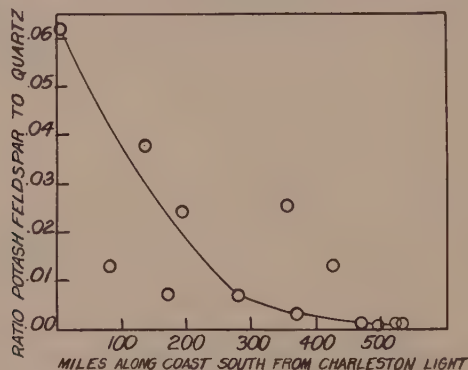


FIG. 1. Variation in ratio of number of potash feldspar to number of quartz grains in beach sands of the Atlantic coast.

other than quartz and feldspar, brings the total feldspar content of that sand to about nine percent. Plagioclase was noted in the other samples in which potash-feldspar is most abundant, and occasionally in some where it is rather scarce. A single grain of oligoclase was observed in sample No. 8049 from Riviera, near West Palm Beach, this being the farthest south that any plagioclase was found.

The diameter of the feldspar grains varies from a few hundredths of a millimeter up to 0.5 mm. They average a little smaller than the quartz grains in the same sand, and are mostly angular to subangular in shape.

The degree of alteration shown by the feldspar grains is usually slight. The largest proportion of grains turbid from alteration, or

having surfaces coated by other minerals, was observed in the sands from Georgia and South Carolina; to the south the proportion of such grains decreases, presumably because the softer altered grains are more easily destroyed by the shocks received in transportation along the beach toward the south. Most of the feldspar grains from the beach sands in Florida are clear and practically free from alteration products, either as coatings or as inclusions.

RELATIVE AMOUNTS OF QUARTZ AND FELDSPAR

The approximate localities of the samples analyzed, the number of grains counted, and the potash-feldspar/quartz ratios are shown in table I. I have expressed the amount of potash-feldspar in the sands examined, as a ratio of the number of potash-feldspar grains to the number of quartz grains, because, by doing so, the variations in the amount of shell and of heavy minerals may be neglected. This may be more briefly referred to as the Kf/quartz ratio. On Fig. 1 are plotted the Kf/quartz ratios in relation to the distance along the coast south from Charleston Light, this being a convenient reference point near the most northerly locality. At Folly Beach near Charleston, S. C., this ratio is .062, at St. Simon Island, Georgia, 130 miles to the south it has decreased to .038, at Manhattan Beach near Jacksonville, about 190 miles to the south, it has still further decreased to .024. Several samples from the vicinity of Palm Beach and Miami, 470 to 520 miles along the coast from Folly Beach, have a Kf/quartz ratio of .001 or a little less.

While the sample from nearest the outcrops of igneous and metamorphic rocks shows the largest amount of feldspar and that farthest away shows the least, the decrease toward the south is far from being regular and uniform. When it is considered that usually only one sample from a locality was analyzed, and that not all of the samples were taken in the same manner, this is not at all surprising. In addition to the effects of transportation by which the less resistant minerals are destroyed to a greater extent, local conditions of sorting have much to do with the proportions of the different minerals. The difference in specific gravity between quartz and feldspar is not great enough so that waves and currents will do much sorting if the grains are about the same size and shape, but there is relatively more feldspar in the fine sand than in the medium to coarse. Therefore, where there is coarser sand at about the upper limit of wave action than there is on the lower part of the

TABLE I
POTASH FELDSPAR IN BEACH SAND IN RELATION TO
DISTANCE ALONG COAST

Fla. Geol. Surv. Sample No.	Locality	Miles along coast from Charleston Light	Grains Potash Feldspar	Grains Quartz	Ratio of Potash Feldspar to Quartz
8079	Folly Beach, S. C.	4	124	2010	.062
8094	Tybee, Ga.	80	64	4760	.013
8032	St. Simon Island, Ga.	135	100	2630	.038
8028	Amelia Island, Fla.	170	22	3080	.007
8025	Manhattan Beach, Fla.	192	56	2300	.024
8041	Daytona Beach, Fla.	283	39	5410	.007
8050	Cocoa Beach, Fla.	354	101	3450	.029
8053	Cocoa Beach, Fla.	354	38	1740	.022
8020	Melbourne Beach, Fla.	371	10	3280	.003
8014	Ft. Pierce, Fla.	422	77	6000	.013
8049	Riviera, Fla.	469	3	3010	.001
8010	Boca Raton, Fla.	498	1	2000	.0005
8009	Hollywood, Fla.	523	6	7100	.001
8001	Miami Beach, Fla.	535	7	6900	.001

beach there may be a much smaller number of grains of feldspar relative to quartz in the coarser material. Some of the local deviations in the Kf/quartz ratio can be explained by the texture as determined by local sorting. As an example of this we may consider two sands from northeastern Florida, one of which was collected from the upper part of the beach and has a Kf/quartz ratio of .007, while the other is a finer sand from the lower part of the beach and has a Kf/quartz ratio of .024. Sample No. 8094 from Tybee probably has a smaller Kf/quartz ratio than normal for that locality, because it contains 4.6% of heavy minerals and in the concentration of these from the smaller average amount in the sand the coarser quartz would go with the heavy minerals, and the finer feldspar would be carried away with the finer quartz. The two sands from Cocoa Beach, which have a much larger feldspar content than those from the nearest localities sampled to the north and the south, have a very fine texture, since nearly seventy percent will pass a sieve with 0.149 mm. square opening. Comparison of sieve tests of many sands with the grain counts made under the microscope leaves no

doubt whatever that the feldspar content is greater in the finer than in the coarser sands.

To get more information about the relation of grain size to distribution of feldspar, counts were made on the several portions into which a sand had been separated by a series of small sieves with openings of 1 mm., 0.5 mm., 0.25 mm., and 0.10 mm., respectively. The results are as given below, showing in another way that the feldspar is distinctly more abundant in the finer sand.

DISTRIBUTION OF POTASH FELDSPAR ACCORDING TO GRAIN SIZE
(Sample No. 8020, Melbourne Beach, Florida.)

Size limits	Number of quartz grains	Number of potash feldspar grains	Ratio of potash feldspar to quartz
0.5 to 1 mm.	Many	None	.0000
0.25 to 0.5 mm.	3860	2	.0005
0.10 to 0.25 mm.	4350	15	.0034
less than 0.10 mm.	3160	90	.0285

W. A. P. Graham² has recently noted a similar relation between texture and occurrence of feldspar in the Cambrian sandstones of Minnesota.

CONCLUSIONS

The decrease in the ratio of feldspar to quartz with increasing distance from the source of the sand is clearly shown by microscopical analyses of sands collected over an interval of more than 500 miles along the beach on the Atlantic coast of the southeastern states. Some feldspar still persists in the beach sand in spite of the low topography near the coast, the fairly warm, humid climate and the derivation of much of the material from sedimentary formations so that it has gone through more than one cycle of erosion. The feldspar in the vicinity of Miami has apparently been transported at least 400 miles along the shore, plus about 200 miles by river. Some of it may have come a much greater distance. The fresh conditions of the few feldspar grains still remaining seems to indicate that the destruction of the feldspar during transportation along the coast has been more by mechanical means than by chemical alteration. Under the conditions prevailing along the Atlantic coast, a fine sand has more feldspar in it than a coarse one which has travelled the same distance.

² W. A. P. Graham, A Textural and Petrographic Study of the Cambrian Sandstones of Minnesota: *Jour. Geol.*, vol. 37, pp. 696-716. 1930.

EFFECT OF LIGHT ON POLISHED SURFACES OF SILVER MINERALS

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INTRODUCTION

The fact that the polished surfaces of certain silver minerals are affected by the light rays from the carbon arc has been known for some time; however, little has been published concerning the details of the reactions.

Any change that occurs on the polished surface of a mineral, due to the action of light or heat from the light source, is called light or heat etching, respectively. The object of the present work was to collect data on light and heat etching and arrange it in a form that could be used in the identification of minerals, when they occur in such small quantities that the usual microchemical tests are unsatisfactory. The problem was suggested by Dr. G. M. Schwartz, of the University of Minnesota, under whose supervision the work was carried out.

The writer is greatly indebted to Dr. J. W. Gruner, Dr. Charles Park, and other members of the Geology Department of the University of Minnesota for help in checking the reactions and for many valuable suggestions. Dr. M. N. Short supplied specimens of pearceite and stromeyerite from the United States Geological Survey collection.

SUMMARY OF PREVIOUS WORK

In 1917 Dr. F. N. Guild¹ published a paper on the silver ores in which he stated that argentite and pyrargyrite were etched by the naked arc light. Proustite did not react. He found that the so-called brongniardite broke down into pyrargyrite as well as other constituents.

Dr. W. L. Whitehead² has studied the common silver minerals under the oil immersion lens, using the standard Leitz metallograph microscope, and has tabulated his results. He showed that argentite, polybasite, pearceite, stephanite, freibergite, and proust-

¹ Guild, F. N., *A Microscopic Study of Silver Ores and Associated Minerals: Econ. Geol.*, Vol. 12, pp. 297-353, 1917.

² Whitehead, W. L., *Technique of Mineralogy: Econ. Geol.*, Vol. 12, pp. 697-716, 1917.

ite were etched by the rays from an arc light. Miargyrite, stromeyerite, cerargyrite, other halides, silver amalgam, dyscrasite and native silver were not altered in 10 minutes. He also stated that the reactions vary greatly in intensity with various specimens, but are, even when obscure, quite typical for each mineral.

Schneiderhöhn³ mentioned that argentite darkens under the action of light and attributes the reaction to the effect of heat.

The halogen silver salts are most affected by the ultra violet, violet and blue rays.⁴ This does not seem true for the silver sulphosalts studied in this problem as will be shown later.

The data concerning the action of light on the various salts are given in publications of Eder's *Jahrbuch für Photographie*, but they are not compiled into tabular form.

METHODS AND EQUIPMENT

Most of the microscopic work of this problem was done with a standard Leitz MM micro-metallograph microscope. The microscope was equipped with an iris diaphragm in the shield between the main condensing lens and the reflecting prism. The diaphragm was completely open for etching, and in some cases the entire shield was swung out of the path of the light beam. Minerals previously reported as negative were found to react when the full strength of the light was applied.

Some of the work was done on a polarizing microscope. This was an ordinary petrographic microscope equipped with a reflecting prism and a horizontal nicol prism. Light was supplied from a 1000 watt filament lamp. The reactions with this microscope took seven times as long as those observed on the metallograph.

Several specimens of each mineral were examined. These came from various parts of the world. In each case the identification of the mineral was checked by the use of the new tables supplied, in manuscript, by Dr. M. N. Short of the United States Geological Survey.

The reactions of the silver minerals to light were first studied under the oil immersion lens, but the changes were often obscured by bubbles forming in the oil. The bubbles probably were due to gas formed by the decomposition of the silver minerals. After working for several weeks with oil immersion lenses, it was decided to

³ Schneiderhöhn, Hans, *Untersuchung Von Erzen: Selbstverlag der Gesellschaft, Berlin*, pp. 207, 1922.

⁴ Communications from the Eastman Kodak Company.

use lower magnification. The 4 mm., 8 mm., and 14 mm. lenses were used but only a few active minerals can be satisfactorily etched with the 8 mm. and 14 mm. lenses. In general, the 4 mm. lens is most satisfactory.

Wratten filters were used to control the rays of the spectrum and a N/2 copper sulphate solution was used when it was desired to eliminate most of the heat. A nickel glass filter was used to absorb the light and transmit the heat rays.

EXPERIMENTAL DATA

LIGHT. The beam of light from the carbon arc may be divided into the heat rays and the rays of the visible spectrum. Schneiderhöhn⁵ believes that the heat rays are more important in light etching while other writers believe the reactions are due to a photochemical effect. Evidence cited below shows that argentite, and most of the silver sulpho-salts seem to be affected by both groups of rays while stromeyerite, andorite, petzite, and probably coloradoite are affected only by the invisible heat rays.

The intensity of the arc light beam was not determined, but reactions occurred in about one-seventh of the time needed for those using the 1000 watt filament lamp as the light source. Thus, the arc light beam probably is equivalent to 6000–7000 watts when the shield is removed from the path of the beam.

The temperature of the arc light beam was not determined but potentiometer readings indicated that the copper sulphate solution absorbed more than five-sixths of the heat. While working on specimens mounted in sealing wax, it was found that the wax melted and appeared to boil when the diaphragm of the shield was wide open. Sealing wax softens in boiling water. Chalcocite, which has an inversion point at 91° C. recrystallized when the shield was removed from the path of the light.

The following Wratten filters were used to absorb the light of various wave lengths; number 76 blue transmitting a band from $\lambda 480\mu$ down, number 75 cyan blue filter transmitting a band from $\lambda 450$ – 520μ , number 74 green filter transmitting a band from $\lambda 520$ – 580μ , and number 70 red transmitting a band from $\lambda 680$ – 720μ +. The width of the transmitted bands were checked by the use of a Zeiss model C hand spectroscope. The red filter, number 70, was found to transmit more heat than the others. A nickel glass filter was used to absorb the light rays but transmit the heat rays.

⁵ Schneiderhöhn, Hans, *Op. cit.*

The results of tests upon several specimens of each mineral are tabulated below.

TIME NECESSARY TO PRODUCE A VISIBLE REACTION

Filter Number	76	75	74	70	Heat Alone (after 1 minute); above 720
Wave Length	480—down	450—520	520—580	680—720	
<i>Mineral</i>					
Argentite	15 sec.	10 sec.	5 sec.	15 sec.	Pits only
Stromeyerite	?	?	25	8	Slight etching
Polybasite	60	45	35	10	Very slight etching

The filters reduce the intensity of the light so much that it is difficult to determine the time of reaction of pyrargyrite, pearceite, or proustite, which are more inactive to light rays than those minerals given in the above table, but they seem to be affected more by light thru the red filter. Chalcocite, petzite, hessite and coloradoite are affected mainly by the heat rays.

The above work on the effect of various wave lengths of light is of a preliminary nature only and should be followed by detailed studies.

It is stated above that the silver haloid salts are most affected by the ultra violet, violet, and blue rays. The above experiments tend to show that the silver sulpho-salts are most affected by waves of a long wave length. The following relationship, therefore, is probably correct though with considerable overlapping.

		Um.	Cy.		Yel-			
Rays	Violet	Blue	Blue	Green	low	Orange	Red	Heat
Wave Lengths	397	431	486	527	589	656	760	+
(in microns)								
Silver haloids most affected.					Silver sulpho-salts most affected.			
Most specimens active		→	Most specimens inactive		←	Most specimens active		

silver, as is suggested by theories of photochemistry, then one would expect the sublimate to be free sulphur, antimony or arsenic trioxide, depending upon the composition of the mineral. This effect is not seen when oil immersion is used, as the sublimate probably goes into suspension in the oil.

Specimens of argentite, polybasite and sometimes stephanite decompose and give a sublimate on the objective lens even though three-fourths of the heat is removed from the light beam.⁶ If the copper sulphate filter, which almost completely removes the heat, is placed across the light beam little or no sublimation occurs. Some decomposition is probably due to the effect of light but apparently the sublimation is caused mainly by the action of heat. The minerals etched by heat alone, however, do not give the deposit on the lens. Thus, it may be concluded that the combined action of light and heat is necessary for the formation of a sublimate under the action of the arc light beam.

The etching produced on the polished surface of a silver mineral is very delicate and any attempt to polish the surface removes the etching.

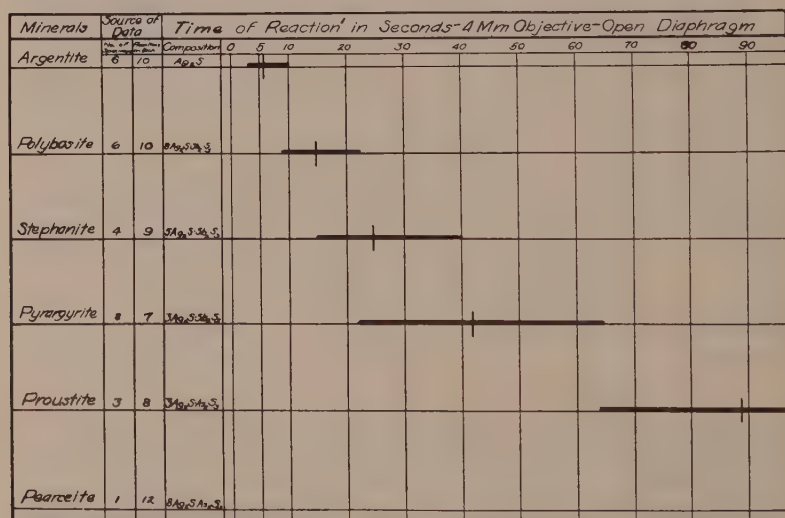


FIG. 1. Variations in reaction speeds of common silver minerals, showing also the range of the reaction speeds in the individual minerals.

¹ Refers to time necessary to produce a visible reaction.

⁶ A 20 mm. water jar is placed across the light beam between the condensing lens and the reflecting prism. This removes three-fourths of the heat according to potentiometer readings.

SPEED OF REACTIONS. The silver minerals etch, or react, at different speeds depending upon the relative stability of the mineral in the presence of light. Fig. 1 shows how the speed of etching increases with the variations of chemical composition of the mineral. These reactions are best observed under the 4 mm. objective lens. The reaction speed of the individual mineral specimen varies considerably due to a difference in the reaction speeds with different orientations of the grains.

If a mineral is etched by light concentrated by an objective of lower magnification than the 4 mm. lens, the speed of the reaction will be less. The more active minerals such as argentite and polybasite will etch under light concentrated by low magnification objectives while pyrrargyrite, pearceite, proustite, and other transparent silver minerals, will etch only by light concentrated by objectives giving high magnification. Thus, the speed of the reaction of a mineral seems to vary directly with: (1) the concentration of light, (2) the concentration of heat, (3) the stability of the mineral to these agents, (4) the transparency of the mineral, (5) the orientation of the mineral grains, and (6) the chemical composition of the mineral. See fig. 2. The following table gives the average time of reaction of many specimens.

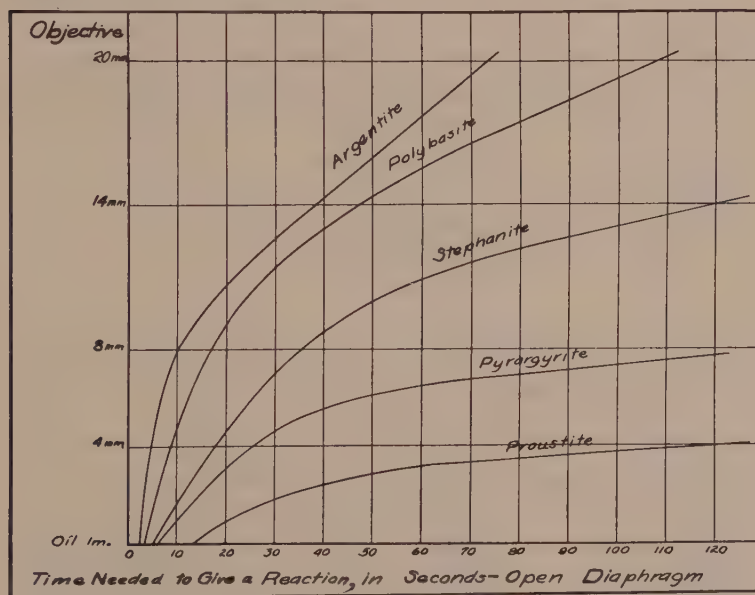


FIG. 2. Curves showing average reaction speeds with various objectives.

TIME IN SECONDS NECESSARY TO PRODUCE A VISIBLE ETCHING

OBJECTIVES	Oil Im.	4	8	14	22 mm.
MINERALS					
Argentite	2	5	10	40	80+
Polybasite	4	6	14	50	100+
Stephanite	6	18	35+		
Pyrargyrite	8	24+			
Proustite	15	120+			
Pearceite	18—	?			

It is impossible to rely on the speed of the reaction alone. This is shown by the fact that some specimens of polybasite react as rapidly as argentite. The etch pattern, however, is quite typical for the various minerals. By considering the speed of the reactions and the etch pattern one may usually identify a silver mineral. The patterns of the minerals are described in detail in the discussion of the individual minerals.

The color of the etch surface will vary in different minerals. The etch patterns of silver minerals are usually shades of gray, but in some cases yellow or silver patterns are obtained. These colors probably are due to the variations in density of the free silver deposited on the mineral surface during the reaction. See the following table.

COLOR OF THE ETCHED SURFACE AFTER EXPOSURE TO LIGHT

MINERAL	Color after 1 minute or less, 4 mm. lens	Color after 2.5 minutes, 4 mm. lens
Argentite	Gray to black	Blue black
Stromeyerite	Gray to yellow (Silver colored in hand specimen)	Same
Polybasite	Gray	Same
Stephanite	Yellow to gray	Light yellow to reddish brown
Pyrargyrite	Yellow gray	Gray
Proustite		Light gray
Pearceite	Sometimes gray, usu- ally negative	Light gray
Andorite	Gray to black pitted	Iridescent to black
Petzite	Gold	Same but coarser particles
Unidentified galena enrichment	Brown	Blue to blue green
Coloradoite	Brown	Blue iridescent, brown edges, sometimes black

The following table shows approximately the action of various minerals under light. It is sometimes necessary to determine whether the etching is caused by heat or light. This is done by the use of the copper sulphate solution filter mentioned above. The speeds given represent averages of many reactions. One would expect variations as is shown in fig. 1.

DESCRIPTION OF MINERALS

ARGENTITE. Argentite is very unstable in the presence of light and heat from the carbon arc. See figs. 1 and 2. The first appearance of the etch pattern is seen along the cracks and scratches of the specimen. The pattern seems to consist of small dashes oriented in two directions so as to form a very fine screen-like pattern. The etching, caused by light alone, usually appears, at first, in small dots over the surface. Shortly after the appearance of the dots a finer etching develops in the spaces between them. The etching grows dense after long exposure. Some specimens show no other action regardless of the amount of heat.

Sometimes when the heat rays are not removed more active specimens show a different pattern. The etching just described takes place very rapidly and in some specimens almost instantaneously. The heat then volatilizes the inner portion of the etched area, forms a group of pits in the center of the field, and causes a heavy sublimate to deposit on the objective lens. Around the pits a band is formed with less conspicuous effect, but on close examination it seems that a change has taken place in the structure of the mineral. This area is anisotropic after etching and shows a bladed intergrowth. Recrystallization occurs, but it is questionable if the inversion point at 175° C. is reached. Outside of this area a dense outer band is formed. See fig. 3. The entire surface exposed to the light beam thus gives a target shaped pattern.

If the center of light is moved so as to fall upon the outer portion of the etching, a volatilization occurs. A central group of pits will form if exposed long enough. Thus, the action of light is probably closely followed by the action of the heat rays. These two reactions take place so rapidly that they appear to occur simultaneously. It is necessary, however, to have the maximum amount of light possible, i.e., the unshielded arc, in order to get the heat reaction described above.

Argentite was also etched by the 1000 watt light. The etched pattern was the same as that formed by the action of the arc light,

TABLE SHOWING REACTION OF MINERALS TO LIGHT

Mineral	Polarized light	Time ¹ of Reaction to Arc Light in Seconds, 4 mm. lens		General Appearance
		Heat and Light	Heat Removed	
Argentite	Slight to neg., anisot.	4	6	Dense etching, heavy sublimate on lens.
Stromeyerite	Strong, anisot.	4	15?	Intergrowth pattern, recrystallization, silver etching.
Polybasite	Fair-good, anisot.	5	5	Spotted surface.
Stephanite	Fair, anisot.	15	30	Brown screen like pattern, not dense.
Pyrargyrite	Fair, anisot.	20	45	Thin etching conc. at edge of field and along scratches.
Proustite	Fair, anisot.	90	Slight after long exposure	More transparent than pyrargyrite. Reactions same.
Pearceite	Strong, anisot.	15+	Slight after long exposure	Reactions same as proustite.
Andorite	Strong	10+ (On edge only)	Neg.	Black pitted center with bright iridescent band at edge of field.
Petzite	Isotropic	6 (When warm)	Neg.	Bright gold etching, expanding and contracting bands during exposure. Cubic cleavage.
Hessite	Fair, anisot.	10±	Neg.	Slight pale yellow film spreads over surface during exposure. Structure later develops.
Coloradoite	Isotropic	20-60	Neg.	Changes to blue, brown, to iridescent along edges only.
Unidentified galena enrichment. With lillianite.		20+	Neg.	Changes from pinkish brown to blue then brown or vice versa.

¹ Refers to the time necessary to produce a visible reaction.

PHOTOMICROGRAPHS OF THE REACTIONS*

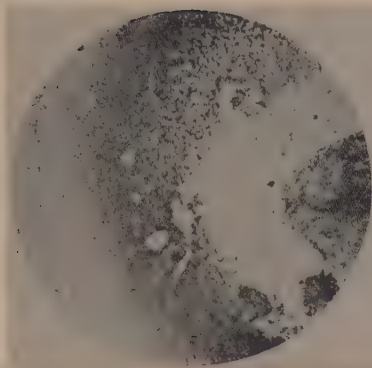


FIG. 3. Argentite etched by both light and heat. The pattern is slightly off center to show the characteristic target shape. The inner and central portions show the effect of the heat rays while the outer portion is caused by the action of the light rays. 4 mm. objective. Mag. 178X.

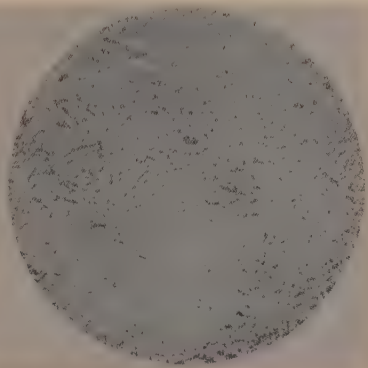


FIG. 4. Stromeayerite showing the typical intergrowth pattern caused by exposing the mineral to the heat and light rays of the carbon arc. 4 mm. objective. Mag. 178X.

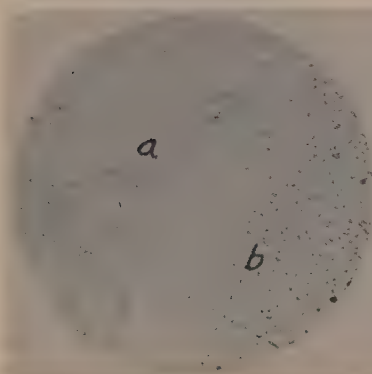


FIG. 5. Polybasite etched by both heat and light. This shows two orientations of the mineral and the patterns of each orientation. 4 mm. lens. Mag. 178X.



FIG. 6. Stephanite etched by both light and heat. The pattern resembles that of pyrargyrite, proustite, and pearceite, but it usually is coarser. 4 mm. lens. Mag. 178X.

* All of the etch patterns are moved off center to show the entire relationship.

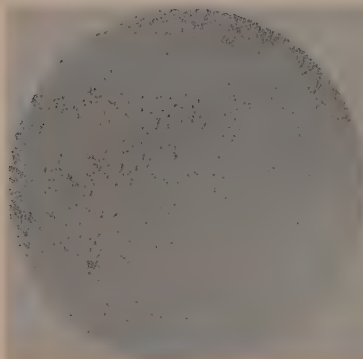


FIG. 7. Pyrrargyrite etched by heat and light. Note the concentration of the elongated dashes (etch marks) along the scratches. This pattern is finer than that of stephanite. 4 mm lens. mag. 178 \times .

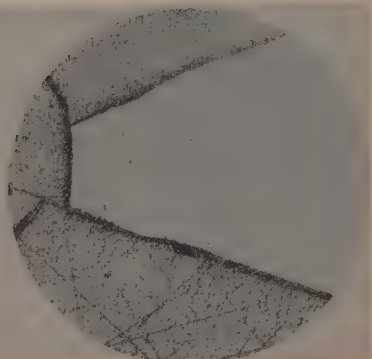


FIG. 8. Proustite in two orientations etched by the action of heat and light. The central grain is just beginning to etch after being exposed for two minutes. 4 mm. lens. Mag. 178 \times .

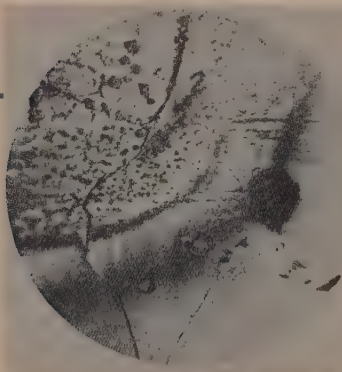


FIG. 9. Andorite etched by the rays from the carbon arc light. The central portion is deeply pitted and fractured, while around this there is a band of red to iridescent colored etching. 4 mm. lens. Mag. 178 \times .

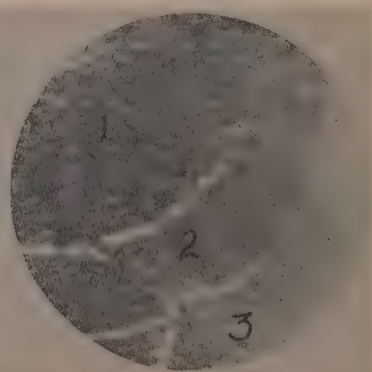


FIG. 10. Petzite after exposure to the heat rays of the arc light. Note the three advances of the etch pattern, and hazy appearance of the etching. 4 mm. lens. Mag. 178 \times .

but the time needed to produce a visible effect was seven times as great as that when the carbon arc is used. By using the oil immersion lens with unpolarized light the etching took place in 10 seconds, and with the polarized light in 18–20 seconds. Little change in the speed of the reaction was noticed when the heat rays were removed. This would indicate that the etching of argentite is not entirely a heat action as Schneiderhöhn⁷ suggested.

A small amount of the sublimate, mentioned above, was collected on a cover glass and found to be soluble in carbon bi-sulphide. Upon evaporation small crystals which seem to be sulphur were formed. Thus, argentite probably decomposed into free silver, left on the surface as an etch pattern, and sulphur, deposited on the lens as a sublimate.

The characteristics of argentite are: the negative to slight anisotropism; the rapid appearance of dots; the development of the fine etching between dots; the target shaped pattern; and the heavy sublimation under the action of light and heat.

STROMEYERITE. Stromeyerite etches rapidly when exposed to the full beam of the arc light. The surface of the specimen turns yellow brown and seems to wrinkle. The etching, shown in fig. 4, resembles a wrinkled skum, but on close examination it shows a pattern suggestive of the intergrowth obtained by Guild⁸ by etching stromeyerite with KCN. The light etched surface, however, looks silver colored in the hand specimen. If the surface is exposed to light for 15 seconds or longer small groups of black dots form suggestive of argentite. These seem to outline grains of stromeyerite. The specimens, however, show a complete absence of a granular structure under polarized light. Thus, the dots etched black are probably intimate mixtures of argentite and stromeyerite or a portion of stromeyerite partly breaking down to form argentite.

When five-sixths of the heat was removed by the copper sulphate solution the intergrowth etching did not form, but the small black dots appeared in 15 to 20 seconds. Thus, the intergrowth-like etching is due to the action of the heat rays, while the spotted etching is due to the action of the light rays.

Considerable change takes place in the specimen during its exposure to the light and heat of the carbon arc. A single large grain uniform under polarized light was observed after exposure to the

⁷ Schneiderhöhn, Hans, *Op. cit.*

⁸ Guild, F. N. *Enrichment of Silver: Lab. Investigation of Ores*, p. 227. McGraw-Hill, 1928.

light beam and found to have developed a fine granular, bladed, or interlocking structure. The small grains show no common orientation, but they do have about the same degree of anisotropism as that shown by the original stromeyerite. This grain structure is best seen if the silver etching is first removed by fine polishing. The granular structure is confined to the portion of the grain exposed to the arc light, and there is a sharp contact between the etched material and the solid unetched surface of the large grain.

The chemical composition of stromeyerite, $\text{Ag}_2\text{S} \cdot \text{Cu}_2\text{S}$, suggests the possibility of a breakdown into argentite and chalcocite. Argentite is unstable in the presence of light and heat while chalcocite has an inversion point at 91°C . a temperature easily reached by the rays from the arc light. Chalcocite, sometimes, shows a crystal rearrangement after short exposure to the light from an arc.

It is difficult to explain the changes that take place in the stromeyerite specimens during the exposure to the arc light. A breakdown of the mineral probably occurs forming a thin layer of chalcocite and argentite. The argentite, in turn, breaks down into free silver and sulphur. Recrystallization of stromeyerite by heat probably causes the development of the grain structure below the etching.

Summarizing, stromeyerite shows very high anisotropism under polarized light. Rapid wrinkling of the surface forming an intergrowth-like pattern, deposition of a bright silver coating on the surface, and the formation of the interlocking grain structure occur upon exposure of the mineral to the arc light beam.

POLYBASITE. Polybasite is rapidly etched by the light rays and may be mistaken for argentite. It is mentioned above that the time of visible etching of the two minerals overlaps, but, in general, polybasite is less sensitive to the arc light than argentite.

The interesting fact about polybasite is that it has two distinct etch patterns depending upon the orientation of the mineral grains. If two grains having different orientations are etched, one will start as fine elongated dashes very closely spaced but uniformly distributed, while the other grain will start as similar marks widely spaced. As the etching progresses the original finely etched surface becomes like that shown in fig. 5a, while the widely spaced etching becomes dotted like that shown in fig. 5b. On long exposure the patterns seem to interchange. The etch pattern shown in 5a will become similar to that of 5b and vice versa. In general, the dotted etched surface is most characteristic of the mineral.

The etching of this mineral seems to be due primarily to the action of the light rays, since the speed of the reaction is unchanged when the heat rays are largely removed. There is no evidence of crystal rearrangement as is seen in other minerals. Thus, the heat action is of little importance.

Polybasite may, therefore, be recognized by its pattern, by its reaction speed, and by its good anisotropism. The anisotropism serves as a criterion in distinguishing polybasite from argentite.

STEPHANITE. This mineral, like many others, can be etched very successfully by the use of objectives giving lower magnification than the oil immersion lens, but the speed of etching is reduced.

Stephanite shows considerable variation in the speed of etching. Some specimens examined etch with the speed of polybasite while others are comparable to pyrargyrite, but the mineral usually etches at a speed between the two.

Stephanite, like pyrargyrite, pearceite, and proustite starts to etch along minute scratches and fractures. The early concentration of the small elongated marks around the border of the field is plainly visible. The etching progresses across the field as small areas or groups of light brown to yellow gray marks. These marks usually outline small diamond shaped areas, but some specimens seem to show more or less rectangular shape. Then these etch marks join to form a screen-like pattern over the surface, visible only on close examination.

Stephanite, also, shows a different reaction speed with different orientations of the crystal grains. This fact was brought out when some grains of a specimen reacted as described above while others showed activity enough to give a thin sublimate on the objective lens. Heat rays cause sublimation and concentration of the screen-like pattern into small black to brown spots after long exposure. See fig. 6. The time of light etching is reduced about half when heat rays are present in the light beam.

Thus, stephanite may be recognized by its speed of reaction, its yellow to brown spotted etching, and its screen-like pattern.

PYRARGYRITE. Pyrargyrite, proustite, and pearceite react to light and give about the same etch pattern. Thus, only a few characteristics of each mineral will be given. In general, the etch pattern of these minerals is like stephanite, but it is slightly finer and concentrated more along scratches.

Pyrargyrite has a dark ruby color generally. The mineral reacts to the carbon arc in about 20 seconds, and gives a delicate etch pattern, when the 4 mm. lens is used. See fig. 7.

PROUSTITE. Proustite is lighter in color and is more transparent than pyrargyrite. The time needed to produce a visible etching under a 4 mm. lens is about 80 to 90 seconds. The mineral shows considerable variation in reaction speed depending upon the orientation of the grains. See fig. 8.

PEARCEITE. Pearceite is similar to proustite except that it seems to be less active. It is negative for two minutes and reacts only slightly after five minutes under the 4 mm. lens. Only one specimen of this mineral was obtainable so that a thorough investigation was impossible. Tests other than the light test probably will be necessary to identify the mineral.

ANDORITE. The first attempt to etch the surface of an andorite specimen was unsuccessful but during later experiments the following data were collected.

The specimen of andorite used in the experiments seems to be pure, and probably has the composition given by Dana for the mineral, i.e., $2 \text{PbS} \cdot \text{Ag}_2\text{S} \cdot 3\text{Sb}_2\text{S}_3$. Tests were first made on the central portions of the mineral surface. These portions did not react to the light beam. Thus, the specimen was reported as negative to light reaction. When examining the sharp edges of the mineral, it was noticed that fracturing and decrepitation took place after a short exposure to the light and heat rays. Portions of the mineral surface sometimes seemed to fly off into space. Usually the reaction is not so violent.

After fracturing of the mineral a melting stage seems to occur. The mass yields as if plastic and turns red; then finally appears to boil. Seemingly large pits are formed; large bubbles of gas rise to the surface of a colorless liquid that is formed on the surface of the mineral. Small black particles are seen churning in the liquid, giving the appearance of a crater of an active volcano. Later examination of the specimen shows many gray to black pits with fused edges, at the point where the etching occurred. A bright red to iridescent band is formed around the outer edge of the pitted area.

Heat rays seem to be responsible for the reaction, since no action occurs with them removed. These rays cause the apparent boiling and decrepitation of the mineral surface. A sticky sublimate containing small fragments of the mineral is found on the lens. The identity of this substance is doubtful, but it is probably sulphur.

PETZITE. Considerable time was spent in determining the reactions of the telluride group. Generally the group is not active to

light, but, petzite, hessite, and probably coloradoite show positive results. Petzite and hessite are identical as to their reactions according to Davy and Farnham's tables; Short's tables indicate that petzite is isotropic and has triangular cleavage pits.

By exposing the polished surface of petzite to the heat waves of the arc light beam a bright orange yellow pattern is produced on the surface of the specimen. The color and luster of the etching strongly suggests free gold, in contrast to hessite which does not give a gold etching.

A reaction occurs rather rapidly with either the oil immersion, 4 mm., or 8 mm. objective lens if the light adjustment is perfect. The reaction starts in the center of the field and spreads rapidly outward in waves. The etching spreads to a certain limit, halts momentarily, then it appears to retreat to the center of the field. The fine deposit of gold left on the surface by the advancing etch pattern melts into coarse gold particles and gives a retreating appearance. These particles seem to be suspended in a colorless liquid.

After the retreat there is a short halt, then a second advancement starts a short distance from the outer edge of the first advance. Thus, a narrow unetched space is left surrounding the portion first etched. Advancement followed by retreat occurs until the entire field is etched. See fig. 10.

Thus, petzite may be identified by its characteristic gold etch pattern, its triangular cleavage pits, and its isotropism. Hessite shows none of these properties.

HESSITE. When hessite is exposed to the heat rays a very pale yellow etching sweeps over the surface. The etching is so delicate and takes place so rapidly that often it is unobserved. After long etching, or exposure, the surface of hessite develops a structure that is suggestive of a rearrangement. No reaction takes place if the heat rays are removed from the arc light beam.

The faint yellow etching that rapidly sweeps across the surface and the later development of the structure are the most characteristic features of hessite.

COLORADOITE. This pink telluride is not very sensitive to the light rays. Along edges there is a change of color from pink to brown, blue, and sometimes iridescent, but only after long exposure to the light and heat rays. This mineral shows no very characteristic test in the presence of the arc light rays.

FREIBERGITE. Freibergite reacts to light rays under oil immersion but the use of lower magnification is too slow. Etching occurs only after long exposure when the 4 mm. lens is used.

UNIDENTIFIED GALENA ENRICHMENT. During a study of the Leadville, Colorado, ores, a narrow band of material surrounding and replacing galena was found to turn from a light brownish white to a blue color in the presence of the heat rays from the arc light. Some areas in the galena were completely replaced by the unknown mineral. These areas upon exposure to the arc light turned brown then a distinct blue color.

DISCUSSION

Schneiderhöhn⁹ believes that the etching of argentite is due primarily to the action of the heat rays from the arc light, while Guild¹⁰ suggests that the light etching, as seen in the silver sulpho-salts, is due to an actinic effect of the light. In general, in the silver sulpho-salts, the action of the light rays seems to be responsible for the formation of the etch pattern, but the heat rays undoubtedly have some effect. The light etching usually appears more rapidly if the heat rays are present. Heat, therefore, acts as an auxiliary agent rather than as the agent itself.

Heat, however, is more active upon minerals with low inversion points than those with high, and more active upon those minerals which are unstable than those which are stable. Such minerals as stromeyerite, andorite, petzite, and hessite are good examples of minerals etching primarily under the action of heat. The effect of light on this group is secondary, and in the case of petzite and hessite the light action is probably negligible.

The explanation of light etching probably lies in the basic principles of photochemistry. Meldola¹¹ stated that the action of light upon metallic compounds such as oxides and salts is, speaking in general terms, a reducing action, so that it is important to remember that the metallic compounds which show the most striking photochemical changes are generally those which are capable of being reduced from higher to lower state of oxidation. If the minerals are reduced by light it is quite probable that the etched pattern is due to an unequal deposition of free silver and is accompanied by the liberation of antimony, arsenic, and sulphur sublimates. Schneiderhöhn¹² suggested that SO₂ is given off from argentite when exposed to light.

⁹ Schneiderhöhn, Hans, *Op. cit.*

¹⁰ Guild, F. N., Personal Communication.

¹¹ Meldola, R., *Chemistry of Photography*, pp. 12, Macmillan & Co., 1889.

¹² Schneiderhöhn, Hans, *Op. cit.*

Light etching, perhaps, is not limited to the silver minerals. Mercury, uranium, iron, and chromium compounds show photochemical effects if an organic compound is present as a reducing agent.¹³ Thus, by introducing the use of a few reducing reagents, harmless to the lens, it may be possible to extend the usefulness of light etching to non-silver minerals.

SUMMARY

In general, the problem of light etching may be summarized as follows:

1. Minerals can be identified by their characteristic reactions to the light and heat rays of the carbon arc.

2. The 4 mm. lens is the most practical objective to use in observing the reactions, but, some minerals will react with light concentrated by objectives giving lower magnification.

3. The polished surface of some silver minerals reacts at a certain speed with the light rays and an etch pattern forms that is typical for the mineral. The speed of the reaction varies, depending upon the orientation of the mineral grains, variations in chemical composition of the mineral, and the magnification of the objective lens used.

4. The pattern produced on the surface of silver minerals upon exposure to the arc light probably results from a deposit of free silver formed by the decomposition of the silver mineral; and some specimens of argentite, polybasite, andorite, and stephanite yield a sublimate thought to be sulphur, antimony or arsenic trioxide, depending upon the mineral composition.

5. The silver sulpho-salts are affected mainly by the light rays with wave lengths between $\lambda 520\mu$ and $\lambda 720+\mu$ of the visible spectra; argentite being most active in the presence of the green rays ($520-580\mu$), while the other minerals are most active in the presence of the orange and red rays ($680-720+\mu$).

6. Heat rays usually speed up the action of the light rays; but, in specimens of petzite, hessite, andorite, and stromeyerite, the heat rays are almost entirely responsible for the reaction that takes place. The heat rays usually act as an auxiliary agent to the light rays.

¹³ Meldola, R., *Op. cit.*

NOTES AND NEWS

DOUBLE VARIATION APPARATUS

D. J. FISHER, *University of Chicago.*

Inasmuch as the Emmons¹ Double Variation Apparatus is now coming on the market,² a brief description of the Lindley microscope-refractometer³ is perhaps in order, as during these stringent times money for both instruments may not be forthcoming. The German outfit, entirely different from the Smith-von Schlichten⁴ in method, consists of three parts to be attached to the ordinary polarizing microscope. These are a refractometer stage, a special objective, and (for adjusting the apparatus) an autocollimating Ramsden ocular.

The stage resembles the Fedorow universal stage in many respects, but of the five movements possible with the standard Fedorow stage, only four are present on the microscope-refractometer, A_1 of Berek⁵ being absent. The stage platform of the latter instrument has an east-west horizontal-axis rotating movement, corresponding to A_4 , and there is a large arc with vernier on the left for reading the angle of inclination to the nearest minute. Inset in the stage platform is a circle with a disc of ordinary glass in the center; this circle may be rotated on an axis perpendicular to the stage platform, corresponding to A_3 . On the edge of this circle and nearly parallel it (the angle of divergence is about 10°) is mounted a pin which may be rotated on its axis and which terminates near the center of the top of the glass disc. This is analogous to A_2 , but has the equivalent of a 360° rotation. A mineral grain is glued to the end of this pin.

In case the grain is so mounted that the pin makes a moderately large angle with all three optic symmetry axes, it is probable that each of these in succession can be brought parallel the axis of the microscope tube; otherwise at least two optic

¹ Emmons, R. C., *Amer. Mineral.*, **XIII**, pp. 504-15, 1928; **XIV**, pp. 414-26 and 441-61, 1929.

² Bausch and Lomb Optical Co., Rochester, N. Y.

³ Scheumann, K. H., *Zwei Hilfsapparaturen für das petrographische Mikroskop; I. Mikroskoprefraktometer nach Lindley: Min. u. petrog. Mitt. (Z. für Krist., usw., Abt. B)*, Bd. **41**, Heft 1, pp. 58-63, 1931. Manufactured by R. Fuess, Berlin-Steglitz (Hugo Meyer & Co., 245 W. 55th St., New York).

⁴ *Amer. Mineral.*, **VI**, p. 38, 1921.

⁵ Berek, M., *Mikroskopische Mineralbestimmung mit Hilfe der Universal-drehtischmethoden*, p. 10, 1924. This is *axis 5* of Winchell, A. N., *Elements of Optical Mineralogy*, Pt. I, p. 224, 1928, since the latter has exactly reversed Berek's order of numbering. Berek's system of numbers should be adhered to, since it has priority, and since letters are not suitable for international use (cf. Reinhard, *op. cit.* in footnote 7, p. 31), and in some cases (e.g., Winchell) are cumbersome, as are Emmons' (*op. cit.*, p. 445) names. The new axis on the latter's modified universal stage should be designated A'_2 to harmonize with Berek.

symmetry axes should be accessible (i.e., in the case where the pin roughly parallels an optic symmetry axis). With the microscope stage and microscope-refractometer platform horizontal, rotating the pin until an optic symmetry plane is vertical and then turning the inset-circle until this plane is north-south brings it into a position such that on inclining the stage platform an optic symmetry axis in this optic symmetry plane is brought parallel to the axis of the microscope tube. Of course both optic symmetry axes in this optic symmetry plane cannot be brought into this position unless before inclining the stage platform each is considerably off vertical. The method of orienting the grain is analogous to that used with the Fedorow stage, but instead of the A_1 - A_2 - A_4 combination of the latter, one uses what is equivalent to an A_2 - A_3 - A_4 combination.

By means of an upper and a lower prism of a system of four prisms, the upper two of which are rotatable and the lower two of which may be shoved laterally (east-west), the path of the light may be changed from the ordinary one to one of grazing incidence with the glass disc.

The objective, which corresponds to a No. 3 in power, ends in an immersion lens shaped like the frustum of a cone. Moreover it carries part of its lens system on a slider, so that by removing this the microscope becomes a telescope. A similarly-constructed objective which however lacks the immersion lens may be used for special purposes.

A dark room is not essential, though for accurate work dim conditions are necessary. The mineral grain mounted on its pin is embedded in a drop of liquid which is held by adhesion to the immersion lens and the glass disc. The index of refraction of the liquid may be varied readily by adding another miscible liquid, by warming,⁶ or by changing the light from the monochromator. When the indices of the liquid and of the mineral (in some definite orientation) just match, as shown by the Becke method, one of the two lower prisms of the stage is shoved in, the slider removed from the objective, and the stage tilted until the border between the bright and dark fields cuts the cross-hair intersection. From the angle reading the value of n for the liquid is determined from a simple graph ($n = 1/\sin \alpha$) which covers the range from 1.32 to 2.10. By changing the positions of the side prisms, and employing a disc of special glass, it is claimed that values as high as $n = 5.0$ may be read. The drop of liquid, bounded above by the plane surface of the immersion lens and below by the plane surface of the glass disc, may be considered to be a prism, the angles between the faces of which may be varied at will, but of course the light-path is always perpendicular to the surface of the immersion lens. Curves drawn indicate that with indices up to 2.6 the readings (carried to the nearest minute) are accurate to from about 3 units in the fourth decimal place to one in the third, depending on the value of n (in general lesser accuracy with larger n).

Shortly before the writer left Berlin last February Dr. Lindley kindly obtained a sample of the apparatus which was in process of manufacture and although this hasty set-up was not in all respects satisfactory, the possibilities of the instrument were demonstrated. By removing the ocular good interference figures were observable. These might be of aid in quickly orienting the specimen.

⁶ Dr. Lindley is perfecting a simple electric heating element which should be available shortly.

Comparing the two sets of apparatus, that by Emmons and that by Lindley, it is clear that each in light of the other has certain advantages and disadvantages. Only the Emmons apparatus in combination with the modified Fedorow universal stage is here considered, as with the ordinary stage this method is greatly limited. The more important advantages of the Emmons method consist in the provision to *rapidly cool* the specimen, even somewhat below the normal laboratory temperature; the very exact temperature control; and moreover, because of the numerous possible movements of the modified universal stage, the ability not only to turn a grain so that its principal optical directions lie parallel to the vibration directions of the nicols, but even to rotate the oriented grain in these two planes. From the point of view of the teacher who wishes to train his students with a certain theory and technique, the writer agrees with Reinhard⁷ that crystal study on the universal stage is of great value in leading to a clear conception of crystal optics.

On the other hand with the Lindley apparatus much higher indices can be measured; also it is expected that much higher temperatures can be obtained, which among other obvious advantages permit the use of high-index melts which at lower temperatures solidify to non-isotropic media. Moreover, one is not limited to certain definite embedding fluids, but may use almost any miscible mixture prepared on the stage to suit the particular grain being studied; even if the fluids used have considerably different boiling points, this is of little importance since almost the very instant the grain is matched the index of the liquid is measured.

Until one has had an opportunity to work at leisure with both instruments, it will be impossible to be certain that it is not desirable to have both. The advantage of the greater simplicity of the Lindley apparatus may be offset by its not being so universally applicable as the Emmons modified stage. This would certainly be true were it less accurate; the relative accuracy of the two instruments is at present unknown to the writer. Emmons⁸ estimates an accuracy of $\pm .0002$ at best, and more commonly $\pm .0005$. The difficulty of learning the technique of preventing a mineral grain from sliding around on a tilting universal stage may be no greater than keeping it glued to the pin. The mineralogist is generally not interested in obtaining the dispersion curves for a specimen, but wishes to determine α , β , and γ accurately for sodium light. These values are read from dispersion curves in the Emmons method. Whether the Lindley apparatus would lead to these results direct with no loss in accuracy and at a saving of time as compared to the method of the preparation of dispersion curves (perhaps substituting dilution of the n -fluid for change in temperature) is unknown, but in case it would, possibly a cheaper source of illumination could be substituted for the arc and monochromator.

ADDITIONAL COMMENTS ON THE DOUBLE VARIATION APPARATUS

R. C. EMMONS, *University of Wisconsin.*

Professor Fisher very kindly sent me a copy of the manuscript of his accompanying description of the Scheumann-Lindley microscope refractometer. Through his

⁷ Reinhard, M., *Universal Drehtischmethoden*, p. 5, Basel, 1931. In this connection the model of a universal stage as figured on page 14 (with index ellipsoids as shown, or with rubber balls on which skiodromes are painted) is of great value.

⁸ Letter dated August 14, 1931.

courtesy and that of the editor these supplementary remarks appear with Fisher's paper. Since Fisher informs me that he has not yet received his own double variation apparatus from Bausch & Lomb he has not had an opportunity to use the equipment except once in the University of Wisconsin Mineralogical Laboratories. There are, accordingly, a few points which I feel should be added descriptive of the double variation apparatus. I myself am quite unacquainted with the Fuess instrument which at the time of writing has not yet reached this country.

The requirements for a suitable determinative technique are becoming more pressing and more clearly defined; especially so as our knowledge increases in the field of correlation of optical constants and chemical composition of crystalline materials. Workers in the allied sciences who are beginning to show interest in determinative technique with a view to using it in their own work commonly find that the lack of accuracy of the routine procedure renders the results somewhat intangible. They are not satisfied with an indefinite statement corresponding with our "olivine," "scapolite," or "epidote," or, to name one of our best, "plagioclase ($ab_{76}an_{24} \pm 5\% ab$)" as an example. Nor are mineralogists remaining satisfied with this type of determination. Our requirements are including more specific information, particularly in the chemistry of the materials we are handling. Although suitable data for our newer needs are not yet available they are accumulating. To use such data necessitates the accurate determination *with confidence* and comparative speed not only of the three indices n_o , n_m , and n_p but of any other constants which are conveniently available. In order to determine the three indices accurately it is necessary to go through most of the steps which are necessary to secure other data of important critical value such as dispersion and crystallographic orientation. It seems fair to assume that as index data of accuracy $\pm .003$ and $\pm .001$ have accumulated in the past, so also will data of accuracy $\pm .0004$ and $\pm .0002$ be accumulated in the future.¹ The value to the research worker of suitably accurate data can scarcely be over-estimated. Although we are not yet able by optical means to determine with satisfactory accuracy the three main constituents (ab, an, or) of feldspar, our most common mineral, yet it appears from preliminary calculations that index data correct to $\pm .0002$ will meet this limitation when properly correlated with analyzed material. It is highly probable, however, that stereographic projections such as those of Duparc and Reinhard² will be an essential accessory, serving to indicate changes in the relative orientation of elements of optical symmetry with respect to crystallographic directions. Other minerals than feldspar will in turn doubtless demand an equally rigorous procedure for their complete understanding. The successful attainment of these worthy objectives will be realized only through the cooperative research efforts of a large number of members of the profession actively interested in the detailed study of mineral and crystalline materials.

¹ Reference is made to V. E. Barnes, Changes in Hornblende at about 800° C. *Am. Mineralogist*, Vol. 15, 1930, p. 393. In this paper Dr. Barnes records 369 mineral index determinations of which 63 are $\pm .0002$, 27 $\pm .0003$, 81 $\pm .0004$, 144 $\pm .0005$ and 54 are of greater error, the maximum being $\pm .0012$; the size of the error is closely related to the color of the material in this case. Some of the material was so strongly absorptive as to be almost opaque except in very minute grains indeed.

² *Mem. Soc. Phys. Hist. Nat. Genève*, XL, 1924. Based on the work of Fedorov and Nikitin.

The development of the double variation principle³ was intended as one step toward a more detailed understanding of minerals. The Bausch & Lomb Optical Co. is manufacturing the equipment as a complete unit (without royalty). A laboratory source of hot and cold water and a waste are necessary in addition. Fuess is offering an entirely different piece of apparatus designed by Professors Scheumann and Lindley, to serve a similar purpose and using some of the same principles. Each equipment must stand on its own merits. A satisfactory comparison cannot be made until both have had considerable use, but there are certain features of each which recommend them, as Fisher has brought out. It is my purpose to add to Fisher's comments, emphasis on some features of the double variation equipment of Bausch & Lomb which seem to recommend it. It would be of interest to have the further comments of Professor Scheumann, also.

1. The refractometer feature of the Scheumann-Lindley apparatus is said by Fisher to be capable of an accuracy of $\pm .0003$ to $\pm .0010$. The standard Abbé refractometer used in the Bausch & Lomb apparatus is capable of an accuracy throughout its range of $\pm .0002$. Index readings on crystalline materials studied by either method discussed here must necessarily be less accurate than the refractometer in the system.

2. I am unable to state the lower limit of size of grain which the Scheumann-Lindley apparatus will accommodate. I should anticipate difficulty in gluing grains smaller than .5 mm. to the end of a needle. The universal stage conveniently handles material one tenth this size.

3. A large proportion of the material in which the petrographer is interested is unavailable or unsuitable in grains larger than .1 mm. in diameter. Colored material such as hornblende must be still smaller to be transparent. Thin edges of large grains, which are opaque inside the edges, normally do not give satisfactory results in Becke line tests if accuracy is desired.⁴ Using a 16 mm. or #3 objective, material .03 mm. in diameter can be worked very nicely with the universal stage. For this purpose Bausch & Lomb carries a smaller hemisphere as a stock item.

4. In the field of higher indices progress has recently been made. Spencer offers a high index Abbé refractometer, to read to 1.84. This is essentially the limit of immersion liquids and it includes all ordinary needs.

5. All known media of high refractive index are considerably colored and are transparent only in thin films, introducing a serious limitation to any method which requires an amount of liquid in excess of that needed to immerse the grain.

6. Fisher mentions that the Scheumann-Lindley instrument gives interference figures. Although I have never been interested in the use of interference figures with the universal stage, since the information they give is so easily available by other routine procedures, yet after reading Fisher's paper I have tested this possibility, thinking that others might agree with him in considering interference figures advantageous. Using topaz (birefringence .009) I find that grains as small as .3 mm.

³ R. C. Emmons, *Am. Mineralogist*, vol. 13, p. 504; vol. 14, p. 414, p. 441.

⁴ This is an empirical fact of observation. The explanation may be that the Becke line in immersion work is due to the lens effect of the grain. In large grains of low transparency the lens effect is greatly reduced.

yield excellent figures. The numerous rotations of the universal stage make it possible to change from one figure to another very easily. These figures were obtained with both low and medium power objectives by removing the ocular.

7. In using the double variation procedure one is limited to certain definite embedding fluids only when the highest degree of accuracy is desired.

To my mind there are two features of the Scheumann-Lindley apparatus which highly commend it. First, the ability to mix liquids on the stage affords still another means of varying the index of the immersion medium. I am eager to test the convenience and especially the effect on the accuracy of this detail of their procedure. Second, Fisher states that Lindley is now working on a heating stage. For moderate temperatures this has already been accomplished, but Fisher expresses the hope that high index melts may be kept molten. If the attendant difficulties do not prove too great (i.e., the problem of gluing the grain, cleaning the lenses between melts, heat damage to the lenses, effect of higher temperatures on the optical and physical properties of minerals) this brilliant idea should lead to an interesting and useful technique which could be applied very widely.

BOOK REVIEW

MICROSCOPIC DETERMINATION OF THE ORE MINERALS, M. N. SHORT, U. S. Geol. Survey, *Bulletin* 825, 1931, 204 pages, 11 plates, 16 figures.

This very comprehensive treatise on the microscopic characteristics of the ore minerals is based on surer foundations than any previous publication of the same kind. The genuineness of each mineral species is given a very critical review and, while the reviewer disagrees with some of the author's conclusions as in the cases of galenobismutite and kallilite, accurate and reliable data are for the first time available on a great majority of the ore minerals. Approximately one-fourth of the bulletin is devoted to a discussion of microscopic technique and physical properties. As earlier text-books have included a considerable proportion of this information, it would seem that this introductory part might have been considerably abbreviated without impairing its value.

A step in the right direction has been taken in eliminating the intermediate grade of hardness. Since there is sufficient range in the hardness of certain mineral species to cause overlapping in the three-class system of soft, intermediate, and hard, it seems inadvisable to attempt anything more than a simple classification into soft and hard minerals as outlined in this bulletin.

Part 3, which makes up the second quarter of the volume, is taken up with an admirably brief discussion of etch reactions followed by a set of determinative tables based on isotropic or anisotropic character, and on etch reactions with the four standard and two supplementary reagents of Davy-Farnham. The use of aqua regia in differentiating such groups as pyrite and sperrylite on the one hand and braunite, chromite, cobaltite, franklinite, hematite, and magnetite on the other, would seem of doubtful value since the first two can be differentiated quite easily from the remainder by other means. Apart from such minor details these tables seem to be well adapted to the use of microscopic investigators of this special class.

The remainder of the bulletin, part 4, gives by far the best résumé published up to date of microchemical methods and their adaptation to this class of microscopic investigation. The last section on specific tests for minerals, though useful for reference, might have been omitted as most of the information contained therein is to be found in other parts of the publication.

The minor nature of such criticisms as are here mentioned can be taken as an indication of the sterling character of this publication. It should find an extended use in all laboratories where microscopic work on ores is carried out.

J. ELLIS THOMSON